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Watershed Handbook. A Management Technique for Choosing Among Point and Nonpoint Control Strategies

Great Lakes Basin Commission, Ann Arbor, MI

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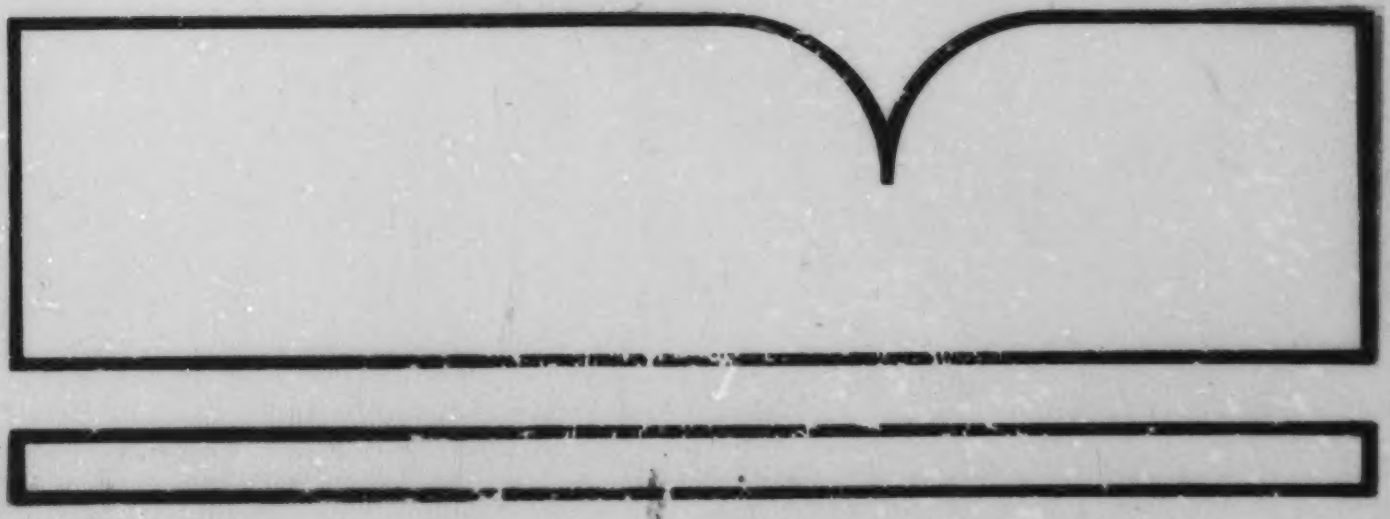

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16. ABSTRACT

Watershed is a simple, "desk top" accounting system designed to help water quality planners assess alternative management strategies for controlling point and nonpoint source pollution inputs from large areas (100 square miles or greater) to a receiving water. Its goal is to find the best mix of point and nonpoint source management techniques to achieve a given load allocation for a receiving waterbody. Through a cost-effectiveness ranking scheme, Watershed identifies the order in which remedial measures could be implemented to achieve the greatest annual water quality improvements at the least cost. This handbook presents the mechanics and background data for using the Watershed system.

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HANDBOOK

a management technique for choosing among point and nonpoint control strategies

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Disclaimer

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WATERSHED HANDBOOK

a management technique for choosing among point and nonpoint control strategies

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summary

WATERSHED is a simple, "desk top" accounting system designed to help water quality planners assess alternative management strategies for controlling point and nonpoint source pollution inputs from large areas (100 square miles or greater) to a receiving water. Its goal is to find the best mix of point and nonpoint source management techniques to achieve a given load allocation for a receiving waterbody. It can be used on one or more river basins at the same time. Through a cost-effectiveness ranking scheme, WATERSHED identifies the order in which remedial measures could be implemented to achieve the greatest annual water quality improvements at the least cost. This handbook presents the mechanics and background data for using the WATERSHED system.

The WATERSHED process has grown out of work completed for the International Joint Commission's Pollution from Land Use Activities Reference Group (PLUARG) study and the Great Lakes Basin Commission's Great Lakes Environmental Planning Study (GLEPS). As part of these projects an analysis similar to what is now called WATERSHED was performed for total phosphorus loads to numerous U.S. tributaries to the Great Lakes. Generally, the magnitude of the calculated phosphorous load compared quite favorably with river mouth water quality sampling data thus encouraging the further development of this process into WATERSHED.

In WATERSHED eight worksheets provide the framework for data organization and analysis. Using the worksheets, the major physical characteristics of the river basin under study are noted and described schematically. Then point source loads, urban runoff loads, and rural noncropland and cropland loads are calculated for various pollutants under both an initial condition and a control program. The cost of the control program is computed and a cost-effectiveness analysis for reducing the pollutant is performed.

In addition to describing the technique, this handbook presents guidelines for interpreting and checking results. The primary method of checking the WATERSHED result is to compare the rivermouth (or sub-basin) pollutant load calculated with that obtained from actual field sampling.

More advanced concepts utilizing WATERSHED are also discussed. Topics include: 1) study of the biologically available fraction of a pollutant; 2) multiple objective analysis using linear programming; and 3) staged or incremental pollutant control strategies.

Various accounting aids including a Fortran computer program are available, but certainly not necessary for the use of WATERSHED. Also, many data sources and typical river basin data are made available in the appendices.

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chapter one
introduction to WATERSHED

Given today's economic constraints (reduced government spending, inflation and high energy costs), water quality managers must make decisions and recommend actions that will cost-effectively achieve their objectives. To control pollution problems the best combination of point and nonpoint water quality control measures must be selected. This handbook and the technique it describes will assist the user in gathering and organizing critical information needed to quantify pollutant loadings within a given drainage area and to subsequently formulate an initial strategy for cost-effectively reducing these loadings. WATERSHED is a simple, "desk top" accounting system for assessing alternative management strategies for controlling point and nonpoint source pollution inputs (excluding atmospheric inputs) from large areas (100 square miles or more) to a receiving water. Its goal is to find the best mix of point and nonpoint source management techniques to achieve a given load allocation for a receiving waterbody. It can be used on one or more river basins at the same time. Through a cost-effectiveness ranking scheme, WATERSHED identifies the order in which remedial measures could be implemented to achieve the greatest annual water quality improvements at the least cost. This handbook presents the mechanics and background data for using the WATERSHED system.

To do this WATERSHED utilizes information on the costs and probable load reductions associated with alternative remedial measures and on the geophysical and demographic characteristics of a drainage area. WATERSHED is unique in that it facilitates the integration of a wide range of technical information on both point and nonpoint pollution control. While it allows the user to quantify and apply information generated from years of research and demonstration programs, it is not meant to replace proper field study. WATERSHED is designed to be used for planning purposes only. It is a tool for making rough assessments of the cost-effectiveness of different pollution control strategies. It is best used to identify or screen those pollutant sources that require additional study. While it is possible to apply the principles of WATERSHED on a smaller scale, other models such as ANSWERS (Beasley *et al*, 1977) or CREAMS (Knisel, 1980) are more appropriate.

While WATERSHED can be adapted to study numerous pollutants, this handbook is geared primarily to phosphorus and suspended sediment loadings. These two pollutants are generally of most concern to nonpoint source management in North America. Chapter 5 of the handbook describes modifications which can be made to accommodate the unique characteristics of other pollutants.

Synopsis of the Watershed Process

The initial step in WATERSHED is to divide the drainage basin to be studied into a set of relatively homogeneous sub-basin units. Point and nonpoint pollutant sources within each sub-basin are then identified and the magnitude of their respective pollutant inputs estimated. An accounting system is then used to route the inputs from their point of entry through a tributary system downstream to a final receiving water (this process can be performed manually or

with the aid of a computer, as described in Chapter 6).

The magnitude of the pollutant loading reaching a downstream location may change as a result of transmission losses (e.g., a reservoir, inland lake or low-gradient flood plain may retain a percentage of the load). These losses are estimated through the application of "transmission coefficients" which reflect the fraction of material which is transported through various stretches of the tributary network. The biologically available fraction of the total pollutant load reaching a downstream receiving water can also be estimated.

Remedial measures can be compared in terms of cost per unit reduction in the pollutant load either at the point of entry to the tributary or at the downstream receiving water. This basic "accounting system" is readily adaptable to various scales of analysis (100 square miles minimum size) and can be as general or detailed as the user desires.

Estimates of pollutant loads (when monitoring data is unavailable) are based on the most recent information available. The universal soil loss equation (USLE) can be used in evaluating the effect of various management techniques on soil loss from agricultural land. Although there is no precise way to predict the amount of sediment or other pollutants actually delivered to a stream from soil loss data, USLE results can be used indirectly to evaluate loadings from agricultural land. Direct field measurements and unit area loads are also used in compiling agricultural loading information.

Eight different worksheets have been developed for compiling river basin data and making the necessary calculations in the WATERSHED process. These worksheets provide a simple sequential procedure for assessing the importance of point and nonpoint sources of pollution within the river basin. The worksheets, in order of use, are listed below:

Worksheet No.	Description
1	Physical Layout
2	Point and Urban Runoff Loads
3	Rural Non-Cropland Loads
4	Rural Cropland Loads
5	Loading Summary
6	Control Program Costs
7	Cost-Effectiveness Analysis
8	Summary of Programs

These worksheets are the framework of WATERSHED and are described in detail in Chapter 2. The user should first understand how to utilize and interpret these worksheets before attempting to employ more advanced techniques such as the computerized version of WATERSHED.

Data Requirements

In order to apply WATERSHED to a given drainage area it is necessary to assemble an information package which describes the geophysical and demographic characteristics of each sub-basin, the type and magnitude of point and nonpoint pollution sources within each area, and the costs and control levels associated with alternative remedial measures.

Loading data are required for all pollutant sources identified. Data are needed on existing or current loads as well as loads expected under different levels of pollution control. Various techniques are provided to estimate loads should actual measurements not be available. Special attention is given to rural runoff pollutant loads. Rural runoff loads are divided into two categories: cropland and non-cropland. Techniques are provided to allow the use of the universal soil loss equation (if desired) to assist in calculating loads from cropland runoff. Whenever

possible several options are provided for determining source loads.

Alternative pollutant control strategies must be formulated for each major point and nonpoint source of pollution. For each control strategy a pollutant load reduction and implementation/operation cost is calculated.

Other data which may be important to the analysis include local water quality regulations or constraints, information on the biological availability of the pollutant(s) under study, and location and trap efficiencies of impoundments located along the tributary system.

Data Sources

WATERSHED is able to utilize a variety of data sources for identifying and quantifying both the pollutant loads and the cost of controlling those loads. Data sources include actual field measurements or studies conducted on the river basin in question, or more general data obtained from the literature or other river basin studies that yield information that can be applied (after adjustment) to the area under investigation. Measured (monitored) data are frequently available for municipal wastewater treatment plants. Either the plants themselves or an appropriate regulatory agency can often supply the loading information and operating cost data. For other pollutant sources (such as urban runoff and rural runoff), estimates must frequently be used. A list of sources to check for measured data is provided in Appendix A. Data compiled from numerous studies of point and nonpoint source pollutant loadings and controls are presented in Appendices B through D. Information presented is primarily for total phosphorus and suspended solids.

chapter two

how to use the WATERSHED process

Synopsis

The worksheets described in this chapter provide the organizational framework for the WATERSHED process. By utilizing these worksheets, the cost-effectiveness of different point and nonpoint control strategies can be compared in a straight-forward manner. The worksheets are used as follows:

Worksheet 1. After the drainage basin is divided into sub-basins and schematically diagramed, the pollutant sources are identified and characterized and entered on the worksheet.

Worksheet 2. Pollutant loads from municipal and industrial point sources and from urban runoff are entered. Anticipated loads from each source under alternative control programs are entered.

Worksheet 3. Pollutant loads from rural noncropland runoff areas are entered.

Worksheet 4. Pollutant loads from cropland with and without control programs in effect are estimated and entered.

Worksheet 5. All loading data (reflecting both existing conditions and the conditions due to alternative control programs) from Worksheets 2, 3, and 4 are summarized.

Worksheet 6. The costs of each control program are entered.

Worksheet 7. The cost-effectiveness of each control program is calculated in terms of the cost per unit reduction in pollutant load at the river mouth. Programs are then ranked according to their cost-effectiveness and the least cost strategy for achieving a specified load reduction is identified.

Worksheet 8. All of the pollution control programs considered are listed in order of their cost-effectiveness, and the cumulative pollution reductions and costs that accrue as the programs are implemented are entered.

Pre-Worksheet Tasks

Before the worksheets are employed, the drainage basin must be subdivided into sub-basins and the pollutant sources identified and characterized. This information is first recorded on a simple map of the basin, and then diagramed schematically. Another task is to formulate strategies for reducing pollution from each source, and to choose a set of strategies for testing on the worksheets.

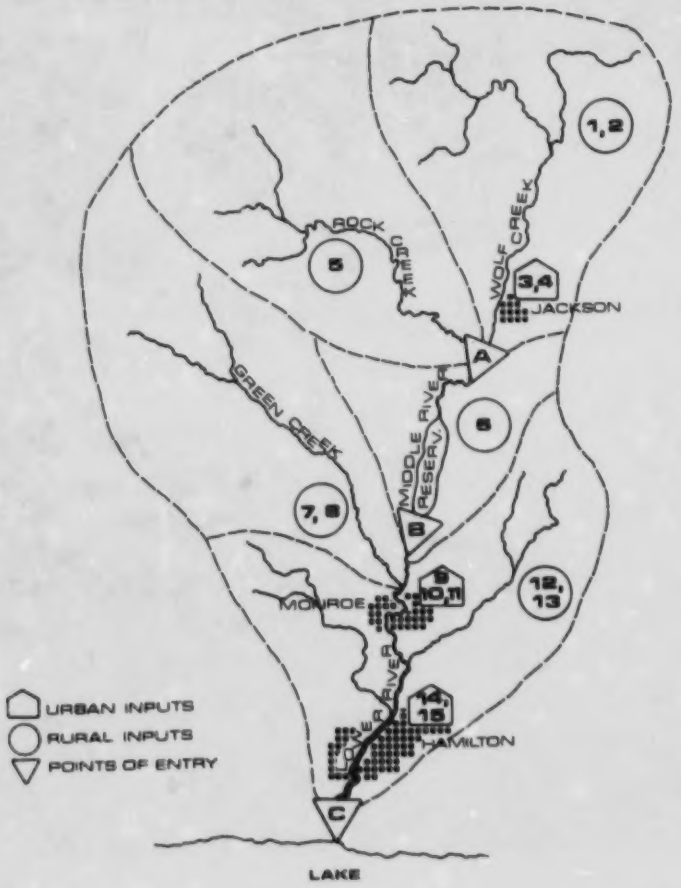
Constructing Sub-Basins

The initial step in establishing sub-basins for a drainage basin is to divide the basin into smaller river basin units. These may be derived from hydrologic maps or other physiographic maps of the drainage area (for possible data sources see Appendix A). Each hydrologic unit is then divided into areas having relatively homogeneous surface soil texture and topography. These areas are referred to as "sub-basins" of the drainage basin under study.

and are designated by dashed lines on the drainage basin map (see Figure 1).

If desired, sub-basins may be further partitioned on the basis of land use intensity (i.e., cropland, pasture, grassland, forest and wetlands) if such data is available. However, this level of refinement is not necessary for application of WATERSHED.

Figure 1
Sample River Basin



Components of the Sub-Basins

After establishing sub-basin boundaries, it is necessary to identify both the point and nonpoint sources of pollution within each and to define the critical characteristics, such as sewered area, land use, and soil type, of both the urban and rural nonpoint sources. This information is needed to accurately assess the magnitude and type of pollutant loadings and the effect of remedial measures.

Point Source Discharges. All significant point sources discharging to surface waters of the sub-basins are identified and each is assigned a number. The location where the pollutant load from each point source enters is then shown on the map as a numbered urban input.

Urban Nonpoint Sources. Urban areas within each WATERSHED sub-basin are identified and the location of each is noted on the map, as shown by the shaded areas in Figure 1. Within each urban unit, the separate storm sewered area, the combined sewered area, and the unsewered area are estimated, and each of these three sources is assigned a number. For cities with a population less than 10,000, it is generally sufficient to only identify and number the total urban area. All these sources are then shown on the map as numbered urban inputs. The area estimates will be entered later on Worksheet 1.

Rural Nonpoint Sources. Land remaining after urban areas have been identified is considered rural land. It is broken down into two general land use categories: 1) cropland (row crops, mixed farming, and pasture) and 2) noncropland (grassland, forest, or wetlands). Specific land uses within these categories are examined when calculating loads and control costs. The area of each in a sub-basin is determined and each is assigned a number. On the map, the cropland

and noncropland components are shown as a single entry for rural land, but each component is represented by its assigned number. It is critical that cropland areas be accurately identified and characterized, because these areas are generally responsible for the greatest nonpoint pollutant load per unit area of rural land and are the focus of rural nonpoint source control programs. These area estimates will be entered later on Worksheet 1.

Points of Entry

Once the sub-basin boundaries have been defined and the major sources of pollutant loadings have been characterized, the point where each pollutant load enters the main stream channel is identified and noted on the map. The WATERSHED methodology assumes that all point and nonpoint pollutant sources within a given sub-basin enter the main channel at a discrete position referred to as a "point of entry." In some cases loadings from several sub-basins may discharge at the same point of entry, as can be seen in Figure 1 where inputs 1 through 5 from two sub-basins discharge at point "A."

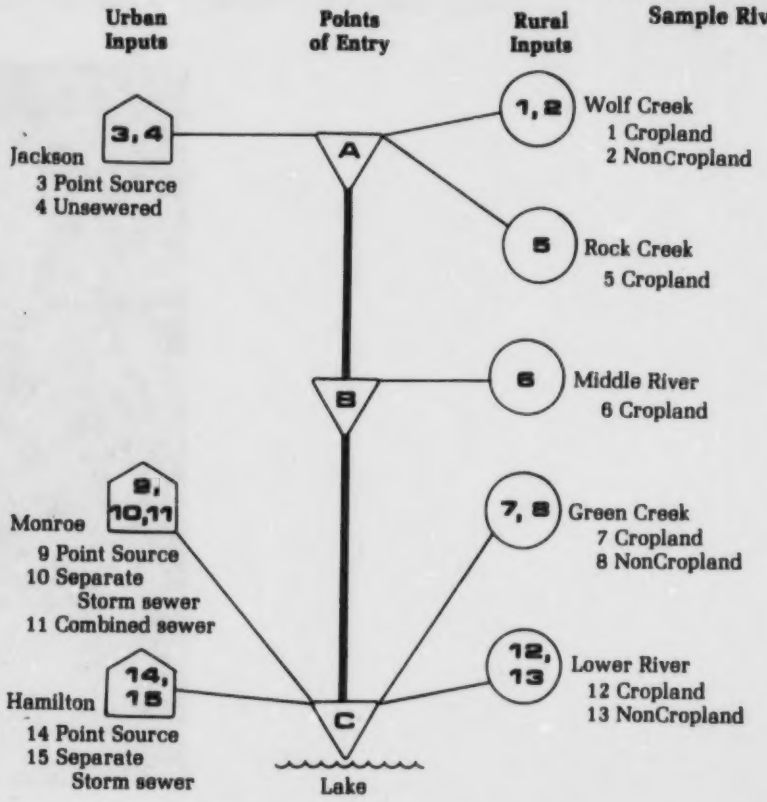
There is no absolute rule for identifying points of entry. This step requires sound judgment and a knowledge of the pollutants under study as well the physical characteristics of the main stream. In general, points of entry correspond to intersections of feeder streams with the main channel or to positions upstream and downstream of river features that could retain material moving downstream (e.g., a reservoir or a low gradient flood plain).

"Transmission coefficients" are assigned to each stretch of river between points of entry. A transmission coefficient represents the fraction of pollutant load that is transmitted from the upstream to the downstream end of the river stretch, and allows the user to account for pollutant losses within the river system. Their use is discussed with Worksheet 7.

Schematic Diagram

Now a schematic diagram of the drainage basin is constructed (see Figure 2). On it, the location and type of pollution sources are listed, and their points of entry shown. The diagram enables the components of the drainage basin and their interrelationships to be more easily conceptualized.

Figure 2
Schematic Diagram of Sample River Basin



Control Strategies

Strategies to reduce pollutant loads are developed now and one strategy for each source is selected for testing on the initial set of worksheets for its costs and effects. (Subsequent worksheet sets may be used to test additional strategies.) While the example in this chapter assumes one control program per strategy, the WATERSHED process also allows for strategies that include several incremental control programs (see Chapter 5, "Advanced Concepts").

To accommodate the need for a variety of measures tailored to the different conditions that may occur in one sub-basin, each program in a strategy may consist of one or more site-specific control measures. For example, to decrease the pollutant contribution from a cropland area, several different tillage variations may be used on individual farms, depending on factors such as the farmer's preference, type of crop, and the characteristics of the land.

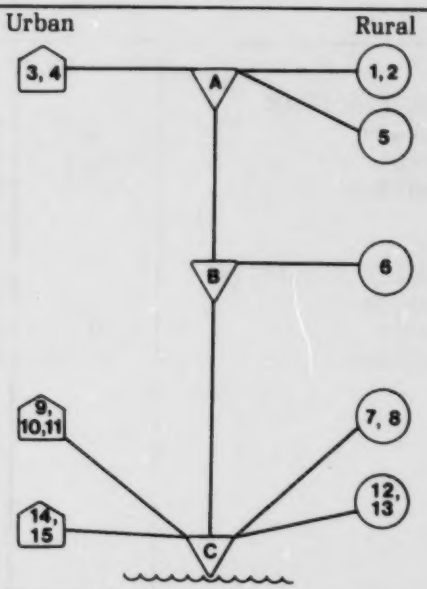
Considerable judgment is required to formulate strategies or control programs tailored to individual situations, so it is important that the water quality manager understand the control measures and how they relate to each other.

Worksheet 1
Physical Layout

Sample River

Source		Position	Point of entry	Area (km²)	Surface Features: Soils	Surface Features: Other
Wolf Creek	Cropland	1	A	250		
	Noncropland	2	A	250		
Jackson Municipal,	Point	3	A	---		
	Unsewered	4	A	15		
Rock Creek	Cropland	5	A	500		
Middle River	Cropland	6	B	250		
Green Creek	Cropland	7	C	300		
	Noncropland	8	C	200		
Monroe Municipal,	Point	9	C	---		
	Separate Storm	10	C	25		
	Combined Sewer	11	C	10		
Lower River	Cropland	12	C	500		
	Noncropland	13	C	50		
Hamilton Municipal,	Point	14	C	---		
	Separate Storm	15	C	60		
TOTAL				2,410		

Diagram



Worksheet 1 displays the physical characteristics of the drainage basin. The "Source" column is used to list each pollutant source identified. Municipal areas may have several categories of point and nonpoint pollutant sources identified on the worksheet: municipal wastewater treatment plants, industrial discharges, combined sewered areas, separate storm-sewered areas, unsewered areas and special contributors such as construction sites. Rural areas may have cropland or noncropland pollutant sources identified.

The next column on Worksheet 1, "Position," is simply used to identify the location of each source relative to the other sources with the same numbers assigned and used in Figures 1 and 2 (lowest number is assigned to the most upstream source).

In column three, the "points of entry," as identified in Figures 1 and 2, are listed in ascending alphabetical order from upstream to downstream location.

In column four, the drainage areas for all nonpoint sources are listed. Areas have been expressed in square kilometers (km²).

Unique surface features that should be noted can also be indicated on Worksheet 1 in columns five and six. For example, unusually steep slopes or the degree of industrialization in an urban area can be noted. It may also be helpful to include the schematic diagram for the river basin (Figure 2) on this worksheet. Various data sources for Worksheet 1 can be found in Appendix A.

Worksheet 2
Point and Urban Runoff Loads

Source	Column ➤	a_1	b_2	c_1	d_2	e_2	f_1	g_2	h_2	i_2	j_2	k_2	l_2
		Point			Separate Storm			Combined			Unsewered*		
	Position	Flow (mgd)	Conc. (mg/L)	Load (kg/yr)	Area (km^2)	UAL** ($kg/km^2/yr$)	Load (kg/yr)	Area (km^2)	UAL** ($kg/km^2/yr$)	Load (kg/yr)	Area (km^2)	UAL** ($kg/km^2/yr$)	Load (kg/yr)
INITIAL CONDITION													
Jackson	3,4	2.0	4.0	11,100	---	---	---	---	---	---	15	250	3,750
Monroe	9,10,11	4.0	4.7	26,000	25	250	6,200	10	900	9,000	---	---	---
Hamilton	14,15	6.2	3.1	26,600	60	250	15,000	---	---	---	---	---	---
CONTROLLED CONDITION													
Jackson	3,4	2.0	1.0	2,800	---	---	---	---	---	---	15	250	3,750
Monroe	9,10,11	4.0	1.0	5,500	25	190	4,800	10	850	8,500	---	---	---
Hamilton	14,15	6.2	1.0	8,600	60	190	11,400	---	---	---	---	---	---

Worksheet 2 is used to compile and organize loading information for all of the identified urban sources of pollution. Whenever possible, measured data from properly designed sampling programs should be used to determine the loads from urban sources. However, measured loadings for nonpoint sources will generally not be available. Methods for estimating these loads are presented here under "Urban Nonpoint Loads." These methods take into account the key factors that have been identified as affecting loads from various sources and represent state-of-the-art knowledge in the nonpoint source pollution field. Although many of the methods are specifically developed for estimating phosphorus and suspended sediment loads, they are applicable to other pollutants. A separate set of worksheets are generally required for each pollutant.

As with Worksheet 1 and the remaining worksheets, the left columns of Worksheet 2 are used to enter the pollutant sources of interest and their position number.

Calculating Costs and Load Reductions

Information reflecting the costs and load reductions for alternative control programs is a major component of WATERSHED and should be developed with care. The appendices give figures for estimating the costs and pollutant load reductions associated with various control programs, but these figures should be seen as only general guidelines, as local conditions differ. Costs, for example vary in different parts of the country and from year to year. The user again has an opportunity to apply judgement and experience, in this case to choose cost and loading data that reflect current conditions for the study area. The application of this data in the WATERSHED process to calculate loads and costs is explained in the subsequent text accompanying the worksheets.

On this and all subsequent worksheets, reference will be made to column letters, subscripted by worksheet numbers. For example, b_2 refers to column b on Worksheet 2.

Point Source Loads (columns a_2, b_2 and c_2)

On this section of Worksheet 2, data on the flow, concentration, and load from municipal and industrial point sources are entered.

Municipal Point Sources. In most cases data on municipal point source effluent loadings will be available for many parameters, and average annual loads can be directly entered in column c_2. If the actual load figure is not available, it can be calculated from average flow and concentration values. These can be entered in columns a_2 and b_2, respectively, and when multiplied by the proper conversion factor, will yield the load value.

Column c_2 across from the "controlled condition" column is also used to insert the point source loads that would occur under various control programs. These are most often improved wastewater treatment programs resulting in a reduced pollutant concentration but sometimes water conservation programs are used, resulting in a reduced wastewater flow. In the example drainage basin, if the Jackson municipal sewage treatment plant had an effluent concentration of 4.0 mg/L total phosphorus (as shown on Worksheet 2) and the control program lowered that concentration to 1.0 mg/L, the new concentration would be entered in column b_2 across from the "controlled condition" entry. The controlled load would then be calculated using the initial flow and entered in the "controlled condition" slot of column c_2. (See example Worksheet 2.) Pollutant loads can

Source	Column ➤	a_2	b_2	c_2
		Point		
	Position	Flow (mgd)	Conc. (mg/L)	Load (kg/yr)
INITIAL CONDITION				
Jackson	3,4	2.0	4.0	11,100
Monroe	9,10,11	4.0	4.7	26,000
Hamilton	14,15	6.2	3.1	26,600
CONTROLLED CONDITION				
Jackson	3,4	2.0	1.0	2,800
Monroe	9,10,11	4.0	1.0	5,500
Hamilton	14,15	6.2	1.0	8,600

average daily flow (mgd) × average concentration (mg/L) × 1.382 = average load (kg/yr)*

*mgd: million gallons per day
mg/L: milligrams per liter
kg/yr: kilograms per year

also be estimated from per capita flows and concentrations found to be typical for different degrees of wastewater treatment. These can usually be obtained directly from sewage treatment plants.

Industrial Point Sources. The initial and controlled industrial values are entered in columns a_2 through c_2 in the same manner as described for municipal sources.

It is recommended that actual plant data be used for important industrial sources, because their often unique wastewaters and specialized treatment technologies make pollutant loads difficult to estimate. However, if measured loads are not available for industrial point sources, estimates can be made if certain characteristics of the industry are known. For example, data on the industrial activity and the amount of process water used can provide some indication of the magnitude of the pollutant load. See Appendix A for specific data sources for industrial point source loads.

Urban Nonpoint Loads

On this section of Worksheet 2, data on the areas of and loads from urban nonpoint sources are entered. The areas can be transferred from Worksheet 1. The loads will have to be determined using computer models or accepted estimating techniques.

There are various computer models that predict pollutant loading from urban runoff (such as STORM, U.S. Army Corps of Engineers, 1975), and the loads calculated using these models can be directly inserted on Worksheet 2. However, if the data requirements for models cannot be met, or should the user desire a less complex approach to estimate urban runoff loads, the **unit area load (UAL)** approach may be desirable.

In the UAL approach, the urban area is first broken down by stormwater collection system (separate stormwater, combined sewer, or unsewered) and by the degree of industrialization (low, medium, high). (The level of industrialization is a factor because pollutant loads generally increase with increased industrial activity, largely due to localized industrial fallout.) Typical UALs for these combinations of urban land are presented in Appendix C, and the areas served by the various collection systems can be obtained from column 3 of Worksheet 1. The load from each source can then be calculated by multiplying the area by the UAL.

Separate Storm Sewered Areas (columns d_2, e_2 and f_2). UALs are selected from Appendix C according to existing levels of industrial activity and entered in column e_2. The separate storm sewer load (in kg/yr) is then calculated by multiplying column d_2 (the area) by column e_2 (the UAL) and is entered in column f_2 (see Monroe and Hamilton in the sample worksheet).

Combined Sewered Areas (columns g_2, h_2 and i_2). UALs are selected from Appendix C and entered in column h_2. Then the combined sewered load (in kg/yr) can be calculated by multiplying column g_2 (area) by column h_2. This value is entered in i_2. (See the City of Monroe in the sample worksheet.)

Appendix C shows that the UALs from combined sewered areas are considerably higher than those from separate storm sewered and unsewered areas for many parameters. This is because when a combined sewer overflows during wet weather bypassing the treatment plant it contains untreated sanitary wastewater in addition to storm water runoff. Combined sewer overflow loads can vary significantly depending on the weather and the design of the collection system. This again calls attention to the need to use local expertise in the WATERSHED process.

Source	Column ▶	d_2	e_2	f_2	g_2	h_2	i_2	j_2	k_2	l_2
		Separate Storm			Combined			Unsewered*		
	Position	Area (km²)	UAL** (kg/km²/yr)	Load (kg/yr)	Area (km²)	UAL** (kg/km²/yr)	Load (kg/yr)	Area (km²)	UAL** (kg/km²/yr)	Load (kg/yr)
INITIAL CONDITION										
Jackson	3,4	---	---	---	---	---	---	15	250	3,750
Monroe	9,10,11	25	250	6,200	10	900	9,000	---	---	---
Hamilton	14,15	60	250	15,000	---	---	---	---	---	---
CONTROLLED CONDITION										
Jackson	3,4	---	---	---	---	---	---	15	250	3,750
Monroe	9,10,11	25	190	4,300	10	850	8,500	---	---	---
Hamilton	14,15	60	190	11,400	---	---	---	---	---	---

Unsewered Areas and Developing Land (columns j_2, k_2, and l_2). The unsewered load (column l_2) is calculated by entering a representative UAL from Appendix C in column k_2 and multiplying it by the area in column j_2 (see the City of Jackson).

Unsewered areas are generally found in regions with little industrial development. In WATERSHED, unsewered areas correspond to (a) urban areas where sewerage systems have not been installed (b) small urban areas where sewer system type cannot be determined, and (c) developing urban land (construction sites). In all of these instances it is assumed that stormwater reaches the receiving stream without the assistance of a sewerage system.

Developing land is a special case in which UALs of sediment and sediment associated pollutants are generally several times greater than those from other urban areas. For example, Johnson *et al.* (1978) reported a value of suspended solids for developing land which is 3 to 5 times greater than the UAL from separate, combined or unsewered areas. Similar high contributions from developing urban land have been reported by Chesters *et al.* (1980) in their extensive study of the Menominee River basin in metropolitan Milwaukee. Developing urban land generally comprises a small portion of the total urban area, but can be important due to the large volume of sediment loading associated with it.

Controlled Condition. The controlled condition for urban runoff is obtained by determining the likely impact a control strategy would have on the unit area load and subsequently inserting the controlled unit area load in the appropriate column on Worksheet 2. For example, a streetsweeping program may reduce the separate stormwater UAL by 25 percent. The reduced value would then be entered in column e_2 and the controlled loading calculated by multiplying column e_2 by the area in column d_2 and entering the result in column f_2 (see the example on Worksheet 2). The same streetsweeping program may only have a five percent impact on the loading from combined sewer overflows. The adjusted UAL value would be entered in column h_2 and the controlled load calculated in a manner similar to the controlled stormwater load.

Worksheet 3
Rural Non-Cropland Loads

Source	Column ►	a_3	b_3	c_3	d_3	e_3	f_3	g_3	h_3	i_3	j_3
		Grass			Woodland			Other**			
	Position	Area* (km^2)	UAL ($kg/km^2/yr$)	Load (kg/yr)	Area* (km^2)	UAL ($kg/km^2/yr$)	Load (kg/yr)	Area* (km^2)	UAL ($kg/km^2/yr$)	Load (kg/yr)	Total Non-Cropland Load (kg/yr)
Wolf Creek Noncropland	2	100	10	1,000	100	10	1,000	50***	0	0	2,000
Green Creek Noncropland	8	50	25	1,250	150	10	1,500	---	---	---	2,750
Lower River Noncropland	13	---	---	---	50	10	500	---	---	---	500
											5,250

The major reason for distinguishing between cropland and noncropland rural areas is that it is generally not desirable to implement a pollution control program on rural noncropland. Grassland, brushland, and forested land usually have a fairly low pollutant load associated with the runoff. It is also very difficult to economically reduce the rural noncropland load. So noncropland rural areas are analyzed only to determine their area and total load. They do not enter into the pollution control strategy evaluation.

Worksheet 3 is designed to facilitate analysis of the rural noncropland loads. On it are spaces for recording the areas, unit area loads, and total loads for different categories of noncropland. Space is also provided for entering the total noncropland load. This value can be obtained from direct measurement, from runoff models, or from unit area loads as given in Appendix D. As with urban nonpoint loads on Worksheet 2, the area and UAL of each source are multiplied to yield the load. This is illustrated on sample Worksheet 3, where the three noncropland areas identified in the sample drainage basin, at positions 2, 8, and 13 are entered.

The "Other" section on Worksheet 3 (columns g_3, h_3, and i_3) provides space for entering minor noncropland categories or special cases. A likely special case could be septic tank failures, which can cause water quality problems if a large number of failures occur near a stream channel. These values can be accounted for in column i_3.

Worksheet 4
Rural Cropland Loads

Source	Column ➤	a.	Universal Soil Loss Equation Coefficients					b.	c.	d.	e.	f.	g.	h.
	Position	Cropland Area (km^2)	Rainfall & Runoff R	Soil Erodibility K	Topographic LS	Cover & Management C	Support Practice P	Soil Loss (t/ac/yr) A	Soil Loss ($mt/km^2/yr$) A	Total Gross Erosion (mt/yr)	Pollutant Delivery Ratio	PRE	UAL ($kg/km^2/yr$)	Total P (kg/yr)
INITIAL CONDITION														
Wolf Creek	1	250	125	.35	.402	.233	1.0	4.1	920	230,000			85	21,250
Rock Creek	5	500	125	.38	.424	.233	1.0	4.7	1,054	527,000			100	50,000
Middle River	6	250	130	.42	.426	.245	1.0	5.7	1,278	320,000			75	18,750
Green Creek	7	300	138	.32	.357	.260	1.0	4.1	920	276,000			75	22,500
Lower River	12	500	138	.38	.381	.260	1.0	5.2	1,116	583,000			60	30,000
TOTAL										1,936,000				142,500
CONTROLLED CONDITION														
Wolf Creek	1	250	125	.35	.402	.108	1.0	1.9	426	106,000	0.0924	0.7	60	13,230
Rock Creek	5	500	125	.38	.424	.099	1.0	2.0	449	224,000	0.0949	0.8	50	27,000
Middle River	6	250	130	.42	.426	.103	1.0	2.4	538	134,000	0.0586	0.9	22	8,940
Green Creek	7	300	138	.32	.357	.108	1.0	1.7	381	114,000	0.0815	0.6	30	14,580
Lower River	12	500	138	.38	.381	.110	1.0	2.2	493	246,000	0.0514	1.0	30	12,680
TOTAL										824,000				76,430

Estimating pollutant loads from cropland is important, because in many areas management of cropland will offer the greatest potential for pollutant reduction from land runoff. Most cropland loads are associated with the soil material. Thus, load estimations often take soil movement into account. Ideally, loads from cropland runoff within each sub-basin would be calculated from field sampling data. However, such data are often unavailable. Further, it is usually not possible to distinguish the pollutant contributions from individual land uses within a sub-basin.

A variety of techniques exist for estimating cropland runoff loads when direct measurements are not available. These include mathematical models, the unit area load (UAL) approach, and the universal soil loss equation (USLE) method. Both the UAL & USLE methods should be used for planning purposes only. The two methods have some drawbacks (to be explained later) that require the user to employ care in their application. Nevertheless, these methods can provide valuable insight into loading from cropland runoff when used for general purposes. Mathematical models are probably the best tool available for detailed nonpoint source load estimates, but they too have limitations. Worksheet 4 is designed to help the user employ any of these techniques for estimating cropland loads.

Mathematical Models

Various deterministic mathematical models exist that allow generation of runoff parameters (Heidtke, 1979; Heidtke and Sonzogni, 1979). Also, there are models such as "ANSWERS" (Beasley *et al.*, 1977) and "CREAMS" (Knisel, 1980), whose results can be directly used in WATERSHED.

Table 1
Total Phosphorus Unit Area Loads for Rural Land

	Total Phosphorus UAL (kg/km²/yr)					
	Type of Soil[a]					
Land Use Intensity	Sand	Coarse Loam	Medium Loam	Fine Loam	Clay	Organic
Rural Cropland						
Cultivated Fields—row crop (low animal density)	25	65	85	105	125[b]	—
Cultivated Fields—mixed farming (medium animal density)	10	20	30	55	85	—
Rural Non-Cropland						
Pasture/Range—dairy	5	5	10	40	60	—
Grassland	5	5	10	15	25	—
Forest	5	—	—	—	10[c]	—
Wetlands	—	—	—	—	—	0

SOURCE: Adapted from Pollution from Land Use Activities Reference Group (PLUARG) (1978). "Environmental Management Strategy for the Great Lakes," International Joint Commission, Windsor, Ontario.

[a]Mainly for midwestern soils. May vary by regions.

[b]Unit area loads may be higher when soil has an unusually high clay content.

[c]Unit area loads may be higher in certain unique forested areas with clay soils.

Unit Area Load Approach

Unit area loads are derived from many different river basins, soils, and climate conditions. The values most often used are for "average" conditions. Because of this the UAL applied in any one study area must be viewed as a general approximation for planning purposes only.

Unit area loads from cropland are often high relative to other sources, although they tend to vary from site to site more than those from other types of land. This variability has been illustrated statistically by Reckhow *et al.* (1980).

One of the principal conclusions from the International Joint Commission's Pollution from Land Use Activities Reference Group (PLUARG) study was that land use is not the only variable influencing pollution from land runoff. Other factors which explain the large range in contributions from single land uses are: land form (e.g., surface soil texture, slope and the chemical characteristics of the soil), land use intensity, materials usage, and meteorology (Sonzogni *et al.*, 1980). The impact that some of these factors have on cropland UALs can be seen in Appendix D. As Table 1 (extracted from Appendix D) demonstrates, surface soil texture is particularly important. How some factors such as materials usage (e.g., amount and technique of fertilizer application) affect UALs is not easily quantified for the general case. Therefore, the values in Table 1 must be tempered by the user's judgment and knowledge of the study area. It is also possible to adjust the UALs in Table 1 to account for differences in the slope of the land. In general, the steeper the slope, the higher the UAL within the same soil texture group. The effect of slope on UALs is described in more detail in Johnson *et al.* (1980).

If the UAL method is selected to estimate loads from cropland runoff, a representative value is first

obtained for each sub-basin from Appendix D. A weighted average for the area may be calculated, depending upon the detail desired. For example, if cropland is comprised of 80 percent row crop and 20 percent close grown crop, the unit area load for row crop would be multipled by 0.8 and added to the quantity 0.2 × the UAL for close-grown crops. This weighted UAL is then placed in column g_i and multiplied by the cropland area (column a_i) to obtain the pollutant load in column h_i.

Loads which reflect implementation of a remedial measure are entered on the worksheet across from the "controlled condition" entry. Programs for controlling cropland phosphorous runoff include basic good stewardship, conservation tillage practices, improved fertilizer management, livestock management, buffer strips, and various structural measures. Appendix D lists typical reductions in UAL values from different cropland controls. Since a control strategy for a sub-basin generally consists of a combination of programs the individual reductions in UALs can be used to calculate a new UAL value for the sub-basin pollutant contribution. This reduced value should be entered in column g_i.

The UAL approach is based on using data from drainage basins similar to the basin under study. This fact must be considered when using this approach. To provide an indication of the sensitivity of the selected UALs, it may be desirable to select a range of UAL values for a particular control strategy. For example, the WATERSHED process could be executed with a controlled UAL in column g_i that is 20 percent less than the initial value. The analysis could then be run once again using a control value 50 percent less than the initial value. A comparison of results would provide an indication of the sensitivity or importance of cropland control in a particular sub-basin. This approach is discussed in more detail in Chapter 5, "Advanced Concepts."

Source	Column ➤	a_i	g_i	h_i
	Position	Cropland Area (km^2)	UAL ($kg/km^2/yr$)	Total P (kg/yr)
INITIAL CONDITION				
Wolf Creek	1	250	85	21,250
Rock Creek	5	500	100	50,000
Middle River	6	250	75	18,750
Green Creek	7	300	75	22,500
Lower River	12	500	60	30,000
TOTAL				142,500
CONTROLLED CONDITION				
Wolf Creek	1	250	60	13,230
Rock Creek	5	500	50	27,000
Middle River	6	250	22	8,940
Green Creek	7	300	30	14,580
Lower River	12	500	30	12,680
TOTAL				76,430

Universal Soil Loss Equation Method

The Universal Soil Loss Equation (USLE) does not allow for directly estimating loads, as does the UAL approach. However, it is a valuable tool in cropland load calculations, because it enables the user to evaluate how a control measure affects erosion. When this kind of information is desired, the USLE can be used together with the UAL approach or other methods for estimating cropland pollutant loads to complete Worksheet 4.

The USLE can be used with a fair amount of confidence to estimate soil loss from small areas for it has been in use for many years, and there is a large amount of well-documented data available from years of research on many soil types.

Calculating Sediment Yield

The USLE cannot be used to directly estimate rural runoff loads because it provides an estimation of the potential gross erosion of soil rather than of a sediment or other pollutant load. That is, the USLE describes the amount of soil that is potentially moved—not the amount of sediment that actually reaches a stream channel. Sediment yield (or load) is usually significantly less than the gross erosion—often in the neighborhood of only 5 to 10 percent of the latter. A factor called the delivery ratio is frequently used to link sediment load with potential gross erosion. Delivery ratio is defined as the ratio of sediment yield to gross erosion.

Unfortunately, there is no established mechanism for estimating sediment delivery ratios. Stewart *et al.* (1975) indicate that the delivery ratio has been observed to be roughly inversely proportional to the 0.2 power of the drainage area (in acres). Such a relationship, because of its exponential nature, makes little distinction in the delivery ratio for basins over 40 to 50 acres in size. Other factors such as surface soil texture, drainage density, and slope may have more significant effect on the delivery ratio than the area drained.

Surface soil texture may be particularly important to delivery. In the Great Lakes basin it has been found that areas with predominantly clay surface soils often have relatively low potential gross erosion rates but high yields of sediments and associated pollutants (PLUARG, 1978). Although McElroy *et al.* (1976) have attempted to relate soil texture to delivery ratio the relationship is not readily usable. A widely applicable equation for pollutant delivery ratios which would allow direct calculations of sediment yield from potential gross erosion remains a major research need.

Calculating Chemical Pollution

Potential gross erosion, as calculated from the USLE, does not provide information on chemical pollution from runoff. The amount of pollutant delivered is often calculated by multiplying the sediment yield by the proportion of chemical contained in the soil sediment and then by an enrichment ratio (Logan, 1980). The enrichment ratio accounts for the fact that the pollutant yield is often a different percentage of the sediment yield than the average percent composition of the pollutant in the soil. Taking phosphorus as an example, an enrichment ratio can be used to account for preferential delivery of clay size particles which, because of their physical and chemical properties, tend to have more phosphorus associated with them than larger particles.

Using Worksheet 4 to Apply the USLE

Although the USLE is most readily applicable to areas of less than 100 acres, in this example and in most WATERSHED applications, it will be applied to

larger areas. To do this the USLE coefficients used must represent averages for different crop conditions. If large scale averaging is not appropriate for a particular area (perhaps because crop types or surface features differ significantly within a sub-basin), the area can be further divided to provide land units appropriate for application of the USLE. This may be done on Worksheet 1 where the initial analysis was completed, or it may be done on Worksheet 4, where a cropland position may be simply split into several pieces. For example, Wolf Creek at position 1 could be divided into Wolf Creek a, b, and c, at position 1a, 1b, and 1c.

Calculating Total Gross Erosion

Ideally, the WATERSHED user would derive unique values for the USLE variables reflecting the specific characteristics of the local study area (see Wischmeier and Smith, 1978). If this cannot be done, some generalized values may be obtained from the literature.

The USLE is applied to each sub-basin to estimate potential gross erosion. For each sub-basin, representative values for the rainfall coefficient (R), soil erodibility (K), topographic conditions (LS), cover and management (C), and support practices (P) are entered on Worksheet 4. These factors are then multiplied together and the product entered as soil loss in tons/acre/year in column b_4. The value in column b_4 is converted to metric tons per hectare in column c_4 ($b_4 \times 224.3 = c_4$). The value in column c_4 is then multiplied by the area (a_4) to yield the total potential gross erosion of sediment in metric tons per year (column d_4).

Source	Column ➤ a_4		Universal Soil Loss Equation Coefficients					b_4	c_4	d_4
	Position	Cropland Area (km²)	Rainfall & Runoff R	Soil Erodibility K	Topographic LS	Cover & Management C	Support Practice P	Soil Loss (t/ac/yr) A	Soil Loss (mt/km²/yr) A	Total Gross Erosion (mt/yr)
INITIAL CONDITION										
Wolf Creek	1	250	125	.35	.402	.233	1.0	4.1	920	230,000
Rock Creek	5	500	125	.38	.424	.233	1.0	4.7	1,054	527,000
Middle River	6	250	130	.42	.426	.245	1.0	5.7	1,278	320,000
Green Creek	7	300	138	.32	.357	.260	1.0	4.1	920	276,000
Lower River	12	500	138	.38	.381	.260	1.0	5.2	1,116	583,000
TOTAL										1,936,000
CONTROLLED CONDITION										
Wolf Creek	1	250	125	.35	.402	.108	1.0	1.9	426	106,000
Rock Creek	5	500	125	.38	.424	.099	1.0	2.0	449	224,000
Middle River	6	250	130	.42	.426	.103	1.0	2.4	538	134,000
Green Creek	7	300	138	.32	.357	.108	1.0	1.7	381	114,000
Lower River	12	500	138	.38	.381	.110	1.0	2.2	493	246,000
TOTAL										824,000

As mentioned previously, the USLE can be used to evaluate how control measures affect potential gross erosion. Extensive literature exists on how control measures such as tillage practices and crop rotation affect the cover factor (C) (Urban et al., 1978; Beasley et al., 1977; and PLUARG, 1978). Information also exists on how measures such as contour plowing and strip cropping affect the practice factor (P), and how terracing can affect the slope length factor (LS). Appendix D provides data for several cropland control programs that reduce potential gross erosion by changing the (C) factor with different tillage or crop rotation practices. By using new values for the (C), (P) or (LS) factors on Worksheet 4 in the "controlled condition" slot, reduced soil loss can be calculated in columns b_4 and c_4, and the reduced total gross erosion in column d_4.

Calculating Total Pollutant Load

At this stage the sediment load (yield) or other pollutant load associated with the sediment must be related to gross erosion so that the initial and controlled pollutant loads can be calculated. There are two basic approaches which will be discussed in detail: 1) the total pollutant load from all sources from each sub-basin is known, 2) the total pollutant load from each sub-basin is not known but the river mouth load is known. In a third situation, where neither the sub-basin load nor the river mouth load is known, the USLE approach can be utilized only to evaluate control practices. Initial condition loads must be calculated using the UAL method in this case.

1. Pollutant Load of the Sub-Basin is Known

The initial or uncontrolled cropland load is obtained by the following equation:

Cropland load = total sub-basin load
− total noncropland load
(*Equation 1*).

This equation merely indicates that a cropland pollutant load can be obtained by subtracting the total noncropland load (both urban and rural) calculated on Worksheets 2 and 3 (columns c_2, f_2, i_2, l_2, j_3) from the measured total sub-basin load (see Table 2 for example). The results from this equation, called "cropland load" in Table 2, are placed in column h_4. These values complete the entries necessary for the initial condition.

To evaluate the controlled condition two more values are needed for each sub-basin: 1) the "pollutant delivery ratio" (column e_4), and 2) the "pollutant reduction efficiency" (column f_4). The pollutant delivery ratio for cropland is described by the following equation:

Table 2
Loads from Sub-Basins Known

Sub-Basin	Position	Total Sub-Basin Load (kg/yr)	Total Non-Cropland Load (kg/yr)	Result Cropland Load (kg/yr)
Wolf Creek	1	38,100	16,850[a]	21,250
Rock Creek	5	50,000	0	50,000
Middle River	6	18,750	0	18,750
Green Creek	7	25,250	2,750	22,500
Lower River	12	113,300	83,300[b]	30,000
		245,400	102,900	142,500

[a]Includes Jackson.
[b]Includes Monroe and Hamilton.

$$\text{Pollutant delivery ratio} = \frac{\text{cropland load}}{\text{cropland erosion}}$$

(Equation 2).

This equation assumes a direct relationship exists between a pollutant load and the amount of material being eroded. The delivery ratio is the link between these two values and is derived by dividing columns d_i (total gross erosion) into h_i (total load). The result is placed in column e_i in the controlled conditions section. The ratio provides an estimate of the kilograms of pollutant delivered to the stream channel per metric ton of soil eroded. This estimate assumes that the pollutant delivery ratio remains constant as the gross erosion is reduced. Because the actual ratio of pollutant delivered to gross erosion is likely to be different with and without control programs in effect, the concept of "pollution reduction efficiency" (column f_i) is introduced here.

Loadings of many sediment-associated pollutants are reduced as gross erosion is reduced, but at different rates. This is because many pollutants have both a soluble and particulate form, and the control of soil erosion will usually reduce the particulate fraction more than the soluble. Taking total phosphorus as an example, if the total phosphorus is 70 percent particulate and 30 percent soluble, a 50 percent reduction in sediment load could reduce the particulate fraction by 50 percent but have little effect on the soluble portion. The pollution reduction efficiency value is designed to reflect this difference. The WATERSHED user may wish to initially ignore this consideration by placing a value of 1.0 in column f_i. Values for this column may be obtained from the literature (Urban *et al.*, 1978; Logan, 1980; Mueller *et al.*, 1981) or estimated by the user. Typical values of the pollution reduction efficiency for total phosphorus would be 0.6 to 0.9.

Source	Column ➤	d_i	e_i	f_i	g_i	h_i
	Position	Total Gross Erosion (mt/yr)	Pollutant Delivery Ratio	PRE	UAL (kg/km²/yr)	Total P (kg/yr)
INITIAL CONDITION						
Wolf Creek	1	230,000			85	21,250
Rock Creek	5	527,000			100	50,000
Middle River	6	320,000			75	18,750
Green Creek	7	276,000			75	22,500
Lower River	12	583,000			60	30,000
TOTAL		1,936,000				142,500
CONTROLLED CONDITION						
Wolf Creek	1	106,000	0.0924	0.7	60	13,230
Rock Creek	5	224,000	0.0949	0.8	50	27,000
Middle River	6	134,000	0.0586	0.9	22	8,940
Green Creek	7	114,000	0.0815	0.6	30	14,580
Lower River	12	246,000	0.0514	1.0	30	12,680
TOTAL		824,000				76,430

Having estimated total gross erosion, the pollutant delivery ratio, and the pollutant reduction efficiency, Equation 3 below is used to estimate the pollutant load delivered to the main river channel assuming a control program is in effect:

Source	Position	d_4 Total Gross Erosion (mt/yr)	e_4 Pollutant Delivery Ratio	f_4 PRE	h_4 Total P (kg/yr)
INITIAL CONDITION		E_i			L_i
Wolf Creek	1	230,000			21,250
Rock Creek	5	527,000			50,000
Middle River	6	320,000			18,750
Green Creek	7	276,000			22,500
Lower River	12	583,000			30,000
TOTAL		1,936,000			142,500
CONTROLLED CONDITION		E_c			L_c
Wolf Creek	1	106,000	0.0924	0.7	13,230
Rock Creek	5	224,000	0.0949	0.8	27,000
Middle River	6	134,000	0.0586	0.9	8,940
Green Creek	7	114,000	0.0815	0.6	14,580
Lower River	12	246,000	0.0514	1.0	12,680
TOTAL		824,000			76,430

$$L_c = L_i - [(E_i - E_c) \times PRE \times PDR]$$

(*Equation 3*).

		Worksheet Column
L_c =	the controlled condition load (mt/yr)	h_4
L_i =	initial pollutant load (mt/yr)	h_4
E_i =	initial gross erosion (mt/yr)	d_4
E_c =	the control condition gross erosion (mt/yr)	d_4
PRE =	pollutant reduction efficiency (unit dimensionless)	e_4
PDR =	pollutant delivery ratio (unit dimensionless)	f_4

In the example river basin, L_c is calculated in the following manner:

Example for Wolf Creek

$L_i = 21{,}250$
$E_i = 230{,}000$
$E_c = 106{,}000$
PDR = 0.0924
PRE = 0.7

$L_c = 21{,}250 - [(230{,}000 - 106{,}000) \times 0.7 \times 0.0924]$
$L_c = 13{,}230$

The controlled cropland loads from each sub-basin are calculated in this manner. Values are entered in column h_4 in the controlled condition section.

Some programs (e.g., voluntary sound land management) do not alter the surface features of the land on which they are applied, so will not show an associated reduction in potential gross erosion on Worksheet 4. However, these programs, such as proper fertilizer application, can still reduce runoff pollutant loadings. These reductions can be subtracted from the values in column h_4 to yield the total cropland load reduction.

2. Pollutant Load from the Sub-Basin is Not Known

In the majority of cases the pollutant load from any given sub-basin will not have been measured. In these situations several techniques can be used for estimating either the load or the pollutant delivery ratio (which may then be used to estimate the pollutant load).

Perhaps the simplest means of estimating the pollutant load is to obtain pollutant delivery ratios from a monitored sub-basin with similar characteristics. If the pollutant delivery ratio can be calculated for a sub-basin using the procedure previously described, this delivery ratio could be used for other sub-basins which are expected to behave in a similar manner.

Another technique is to estimate cropland pollutant loads based on the sub-basin cropland area and the appropriate UAL. The UAL technique for the initial condition would be the same as described previously. The pollutant delivery ratio could then be estimated from Equation 2 and used for the controlled condition on Worksheet 4.

Finally, an estimate of the cropland pollutant delivery ratio can be obtained when the total river mouth load is known (as opposed to the sub-basin load) and no in-stream pollutant transmission losses are likely to occur. River mouth data frequently exist since river mouth monitoring programs are common. In this case, the total noncropland load for the entire basin is subtracted from the total river mouth load to provide an estimate of the cropland load for the entire basin (see Table 3). The total noncropland load would consist of the sum of the values from Worksheets 2 and 3, combining pollutant contributions from urban and rural sources not related to cropland (i.e., the cropland load is that portion of the river mouth load that is not already accounted for on Worksheets 2 and 3).

A cropland pollutant delivery ratio is then calculated for the entire river basin by dividing the cropland load by the cropland total potential gross erosion (the summation of column d_c). These calculations are identical to those presented in equations 1, 2, and 3 except that they are carried out for the entire basin instead of a single sub-basin.

Source	Column ► Position	d_c Total Gross Erosion (mt/yr)	e_c Pollutant Delivery Ratio	f_c PRE	g_c UAL (kg/km²/yr)	h_c Total P (kg/yr)
INITIAL CONDITION						
Wolf Creek	1	230,000			85	21,250
Rock Creek	5	527,000			100	50,000
Middle River	6	320,000			75	18,750
Green Creek	7	276,000			75	22,500
Lower River	12	583,000			60	30,000
TOTAL		1,936,000				142,500

Table 3
Loads from River Mouth Known

	kg/yr
Total River Mouth Load	245,400
Total Non-Cropland Load	– 102,900
Total Cropland Load	142,500

The resultant pollutant delivery ratio represents an average for the entire river basin. This pollutant delivery ratio is entered in column e_i and can be used for each of the sub-basins, provided their characteristics are similar and pollutant inputs do not undergo significant transmission losses before reaching the river mouth.

By multiplying the pollutant delivery ratio (e_i) by total gross erosion (d_i) for each sub-basin, an estimate of the pollutant load from each sub-basin can be generated and entered in column h_i. If application of the pollutant delivery ratio concept is inappropriate because sub-basin characteristics vary or there is a significant transmission loss, the UAL approach must be used.

The pollutant loading with control programs in effect is obtained using Equation 3 with the basin-wide pollutant delivery ratio (e_i), the pollutant reduction efficiency from each sub-basin (f_i) and the estimated gross erosion for each sub-basin (d_i). These values are entered as the controlled load in column h_i.

Source	Position	d_i Total Gross Erosion (mt/yr)	e_i Pollutant Delivery Ratio	f_i PRE	g_i UAL (kg/km²/yr)	h_i Total P (kg/yr)	e_i Pollutant Delivery Ratio	h_i Total P (kg/yr)
INITIAL CONDITION								
Wolf Creek	1	230,000			85	21,250	0.0736	16,930
Rock Creek	5	527,000			100	50,000	0.0736	38,790
Middle River	6	320,000			75	18,750	0.0736	23,550
Green Creek	7	276,000			75	22,500	0.0736	20,310
Lower River	12	583,000			60	30,000	0.0736	42,910
TOTAL		1,936,000				142,500		142,490
CONTROLLED CONDITION								
Wolf Creek	1	106,000	0.0924	0.7	60	13,230	0.0736	10,540
Rock Creek	5	224,000	0.0949	0.8	50	27,000	0.0736	20,950
Middle River	6	134,000	0.0586	0.9	22	8,940	0.0736	11,230
Green Creek	7	114,000	0.0815	0.6	30	14,580	0.0736	13,160
Lower River	12	246,000	0.0514	1.0	30	12,680	0.0736	18,110
TOTAL		824,000				76,430		73,990

Worksheet 5
Loading Summary

Source		Column ➤	a_s	b_s	c_s	d_s	e_s
		Position	Initial Load to River Channel (kg/yr)	Load to River Channel with Controls in Place (kg/yr)		Load Reductions (kg/yr)	
				Stage I	Stage II	Stage I	Stage II
Wolf Creek	Cropland	1	21,250	13,230		8,020	
	Noncropland	2	2,000	2,000		0	
Jackson Municipal,	Point	3	11,100	2,800		8,300	
	Unsewered	4	3,750	3,750	Not Applicable	0	Not Applicable
Rock Creek	Cropland	5	50,000	27,000	(NA)	23,000	(NA)
Middle River	Cropland	6	18,750	8,940		9,810	
Green Creek	Cropland	7	22,500	14,580		7,920	
	Noncropland	8	2,750	2,750		0	
Monroe Municipal,	Point	9	26,000	5,500		20,500	
	Separate Storm	10	6,200	4,800		1,400	
	Combined Sewer	11	9,000	8,500		500	
Lower River	Cropland	12	30,000	12,680		17,320	
	Noncropland	13	500	500		0	
Hamilton Municipal,	Point	14	26,600	8,600		18,000	
	Separate Storm	15	15,000	11,400		3,600	
TOTAL			245,400	127,030		118,370	

The purpose of this worksheet is to compile data from the previous three worksheets (Numbers 2, 3, and 4) and to generate load reductions attributable to alternative control programs. This load reduction data will be vital in determining the cost-effectiveness of the various control programs (Worksheet 7).

Data on initial loads are compiled in column a_s, "Initial Load to River Channel." This is obtained from columns c_2, f_2, i_2, l_2, j_3, and h_4, which give the total urban, rural noncropland, and cropland loads. These initial loads are summed to provide an estimate of the total pollutant input to the river system. This value should equal the river mouth load if no transmission losses occur throughout the system.

Subsequent columns on Worksheet 5 are used to estimate pollutant loadings with control programs in effect. (To simplify the discussion, only one control condition will be considered here. Multiple "stages" of control will be examined in Chapter 5.) Column b_s, "Load to River Channel with Controls in Place" provides space to compile the data on controlled loads. These are also obtained from columns c_2, f_2, l_2, j_3, and column h_4. The sum of all values entered in column b_s yields an estimate of the total load to the river system with control programs in effect. Again, this load is equivalent to the controlled load at the river mouth if no transmission losses occur.

The final step on this worksheet is the calculation of the load reduction due to control programs. This is accomplished in columns d_s and e_s. (Because only one stage of control is being examined at this time, only column d_s will be discussed). The load reduction (d_s) is simply the difference between the initial (a_s) and controlled (b_s) loadings.

Worksheet 6
Program Costs

Source	Column ➤	a_e	b_e	c_e	d_e	e_e	f_e	g_e	h_e
		Nonpoint			Point			Total Cost of Program ($/yr)	
			($/km²/yr)			($/cap/yr)			
	Position	Area Treated (km²)	Initial to Stage I	Stage I to Stage II	Units Served	Initial to Stage I	Stage I to Stage II	Initial to Stage I	Stage I to Stage II
Wolf Creek--Cropland	1	250	65		---	---		16,250	
--Noncropland	2	---	---		---	---		---	
Jackson--Municipal	3	---	---		13,000	2.4		31,200	
--Unsewered	4	---	---		---	---		---	
Rock Creek--Cropland	5	500	65		---	---		32,500	
Middle River--Cropland	6	250	65		---	---		16,250	
Green Creek--Cropland	7	300	65	NA	---	---	NA	19,500	NA
--Noncropland	8	---	---		---	---		---	
Monroe--Municipal Point	9	---	---		25,000	2.4		60,000	
--Separate Storm	10	25	7,500		---	---		187,500	
--Combined Sewer	11	10	7,500		---	---		75,000	
Lower River--Cropland	12	500	65		---	---		32,500	
--Noncropland	13	---	---		---	---		---	
Hamilton--Municipal Point	14	---	---		40,000	2.4		96,000	
--Separate Storm	15	60	7,500		---	---		450,000	
TOTAL								1,016,700	

Up to now pollution control programs have been discussed only in terms of their ability to reduce pollutant loads. At each major source of pollution a control strategy has been identified and a load reduction determined [Worksheet 5 (columns d_e and e_e)]. The objective of Worksheet 6 is to derive a corresponding cost for those programs. (Chapter 5 presents a further discussion of computing costs when multiple benefits are obtained from control programs.) The cost of Stage II programs (columns c_e, f_e, h_e) are not applicable to the example given, but are provided for a more detailed analysis and also discussed in Chapter 5.

Estimating costs can be done in several different ways. In some cases the cost of a particular program may be known and can be entered directly into column g_e, "Total Cost of Program." However, in most instances it will be necessary to estimate program costs from more general information. Worksheet 6 has been set up to provide flexibility in accomplishing this task.

Costs for Controlling Nonpoint Sources

Urban

Costs for control of nonpoint sources are frequently expressed on a per unit area basis. To derive the total cost control at each urban pollutant source, the areas served by combined and separate sewer systems and the urban unsewered areas are entered in column a_s, and the costs per unit area for pollution control at each source are entered in column b_s (or c_s if applicable.) (Values for this example are found in Appendix C, which provides cost information for the urban programs selected for Worksheet 2.) Then the values in columns a_s and b_s are multiplied to determine the total cost of control at each source.

Noncropland

As discussed with Worksheet 3, comprehensive control programs generally will not be considered for rural noncropland since runoff from these areas usually has a low pollutant load. When there are programs in rural noncropland areas, they are usually site-specific rather than uniformly applied. If programs such as drainage projects or streambank stabilization projects exist, it is possible to estimate their costs and treat them as point sources, as discussed in the next section.

Cropland

Computing costs for controlling runoff loadings from cropland is one of the more difficult tasks of the WATERSHED process. Part of the difficulty stems from the fact that individual remedial measures are frequently applied for reasons other than water quality protection or improvement. For example, conservation tillage practices are often implemented to save the farmer time and to conserve soil. In application of WATERSHED, the costs of reducing cropland loadings should be apportioned to the benefits derived from various programs to yield a more realistic cost-benefit comparison. This technique will be discussed in Chapter 5.

Appendix D contains data for several cropland control programs. The information is based on recent findings of studies such as the Lake Erie Wastewater Management Study (Urban *et al.*, 1978), the Black Creek Study (Beasley *et al.*, 1977) and the PLUARG Study (PLUARG, 1978). These costs are expressed on a per unit area basis so they can be entered directly in column b_s. The total cost (to be entered in column g_s) can be computed by multiplying the values in column b_s by the area in a_s.

Calculating Education and Training Costs. Most changes in farming practices that will improve water quality (such as chisel plowing, winter crop covers, crop rotations, or buffer strips) are achieved through education and technical assistance. The only cost of such a program, therefore, is the technical personnel and overhead required to operate such a program or an associated demonstration project. The Black Creek (Indiana) and Honey Creek (Ohio) demonstration programs have shown how important education and technical assistance are for the implementation of these measures. Experience from these programs has indicated that demonstration plots are often desirable for only a short time (three to five years). After this, farmers in the area have either accepted or rejected the new techniques. If the techniques are accepted, farmers who observed or participated in such demonstrations will share their experience with other farmers. Operational farms can be used to demonstrate the new techniques and train other farmers.

In estimating the costs of education and technical assistance programs, the WATERSHED user should have a basic understanding of what types of pro-

grams are appropriate for the area. It is vital to obtain local support in such an undertaking.

The following example illustrates how costs for such a technical assistance program could be derived. Assume a demonstration and technical assistance program is to be operated over a three year period. Also assume that the effort would reach farmers who are responsible for 35,000 hectares of cropland. Table 4 illustrates how the costs for technical assistance can be derived. Salary and overhead, demonstration plot costs, and equipment rental costs are all included. The capital cost is amortized over twenty-five years at a ten percent interest rate and added to O & M costs to yield an annual cost of $23,000. The equivalent cost expressed on a unit area basis is $0.65/ha ($65/km²) (this assumes that 35,000 hectares are actually influenced by the technical assistance). This $65/km² figure is used in the example worksheet in column b_s, for cropland. Even though the demonstration program has a goal of achieving implementation of conservation tillage on 35,000 hectares of cropland in the area, additional areas may also be influenced. For example, if the total cropland area affected is 200,000 hectares, the annual cost of technical assistance would be reduced to $0.12/ha.

Table 4
Estimation of Technical Assistance Costs for Implementing the Minimum Tillage and Crop Rotation Program

3-year program
125 ha of demonstration plots
Goal of 35,000 ha converted to minimum till

Yearly Costs	
Salary and overhead	$ 38,500/yr
Demonstration plot costs	$ 25,000/yr
Equipment rental	$ 6,500/yr
Yearly TOTAL:	$ 70,000/yr
3-year TOTAL:	$210,000
10% interest amortized over 25 years	$23,000/yr
Cost per ha considering only demonstration plots: $23,000/yr ÷ 125 ha	$184/ha-yr
Cost per ha if 35,000 ha converted to minimum till: $23,000/yr ÷ 35,000 ha	$0.65/ha

Other Costs. Program costs in some critical areas may also include financial incentives to encourage farmers to try the new techniques or subsidies to those operators who may actually lose money if they change their operational procedures. The latter can occur in areas where soils are not conducive to some conservation tillage practices.

Costs for Controlling Point Sources

Total costs are often directly available for controlling loadings from municipal and industrial point sources. If not, cost information can frequently be obtained from the treatment plant on a per unit basis (i.e., population served, industrial units produced, gallons treated), or Appendix B can be used to obtain typical costs. In the latter case, the units served can be entered in column d_e and costs per unit served can be entered in columns e_e and f_e. Total program costs are then obtained by multiplying column d_e by column e_e (or f_e, if appropriate) and placing the result in column g_e. For the three example cities, a cost of $2.40/cap/yr was selected as representative for a phosphorus removal program (see column e_e).

Column ➤		d_e	e_e	f_e	g_e
Source		Point			Total Cost of Program ($/yr)
	Position	Units Served	($/cap/yr) Initial to Stage I	($/cap/yr) Stage I to Stage II	Initial to Stage I
Wolf Creek--Cropland	1	---	---		16,250
--Noncropland	2	---	---		---
Jackson--Municipal	3	13,000	2.4		31,200
--Unsewered	4	---	---		---
Rock Creek--Cropland	5	---	---		32,500
Middle River--Cropland	6	---	---		16,250
Green Creek--Cropland	7	---	---	NA	19,500
--Noncropland	8	---	---		---
Monroe--Municipal Point	9	25,000	2.4		60,000
--Separate Storm	10	---	---		187,500
--Combined Sewer	11	---	---		75,000
Lower River--Cropland	12	---	---		32,500
--Noncropland	13	---	---		---
Hamilton--Municipal Point	14	40,000	2.4		96,000
--Separate Storm	15	---	---		450,000
TOTAL					1,016,700

Worksheet 7
Cost-Effectiveness Analysis

Source	Position	a, Effective Transmission	a, Bio-Available Fraction	b, Total Load to Surface Water (kg/yr)	c, Load at Mouth (kg/yr)	d, Load Reduction at Mouth (kg/yr)	e, Cost of Program ($/yr)	f, Cost Per Unit Removed at Mouth ($/kg)	g, Cost-Effective Rank
Wolf Creek Cropland	1	1.0		21,250	21,250	8,020	16,250	2.0	4
Noncropland	2	1.0		2,000	2,000	0	---	---	--
Jackson Municipal, Point	3	1.0		11,100	11,100	8,300	31,200	3.8	7
Unsewered	4	1.0		3,750	3,750	0	---	---	--
Rock Creek Cropland	5	1.0		50,000	50,000	23,000	32,500	1.4	1
Middle River Cropland	6	1.0		18,750	18,750	9,810	16,250	1.6	2
Green Creek Cropland	7	1.0	NA	22,500	22,500	7,920	19,500	2.4	5
Noncropland	8	1.0		2,750	2,750	0	---	---	--
Monroe Municipal, Point	9	1.0		26,000	26,000	20,500	60,000	2.9	6
Separate Storm	10	1.0		6,200	6,200	1,400	187,500	133.9	10
Combined Sewer	11	1.0		9,000	9,000	500	75,000	150.0	11
Lower River Cropland	12	1.0		30,000	30,000	17,320	32,500	1.9	3
Noncropland	13	1.0		500	500	0	---	---	--
Hamilton Municipal, Point	14	1.0		26,600	26,000	18,000	96,000	5.3	8
Separate Storm	15	1.0		15,000	15,000	3,600	450,000	125.0	9
TOTAL				245,400	245,400	118,370	1,016,700		

The previous worksheets have helped the user organize information concerning each major pollutant source in the drainage basin. Worksheet 7 draws this information together so that control programs can be compared and ranked according to their cost-effectiveness in reducing pollutant loads at the downstream receiving water. New information derived on Worksheet 7 so that cost-effectiveness can be calculated includes the load and load reduction at the river mouth, and the cost per unit of pollutant removed at the mouth.

It is recommended that all pollutant sources be listed on Worksheet 7, although only those being considered for control will enter into the cost-effectiveness analysis. By listing information on all sources, the user can evaluate the total basin load to the river and the river mouth and the proportion of the total load that is eliminated by control measures.

Effective Transmission (column a_7)

To calculate the load at the river mouth, the amount of pollutant lost between the point of entry and the river mouth must be taken into account. At the beginning of Chapter 2 the concepts of transmission loss and transmission coefficients were introduced, with the "transmission coefficient," describing the fraction of pollutant load transmitted between any two points of entry. Each reach of the river (section of river between two points of entry) has a transmission coefficient (t) associated with it. The transmission coefficients are used to calculate the "effective transmission," which is the fraction of the pollutant load that is transmitted from the point of entry to the river mouth.

The concept of transmission is further illustrated in Figure 3. If the transmission coefficient t_1 has a value of 0.5 (50 percent of the pollutant load entering at point A is lost by the time it reaches point B) and t_2 equals 0.8 (20 percent loss), the effective transmission of the pollutant load entering at point A (T_A) would be 0.4 ($T_A = 0.5 \times 0.8$). Thus, if the pollutant load introduced at point A were 100 mt/yr, only 40 percent, or 40 mt/yr, would reach the downstream receiving water. At point of entry B the effective transmission T_B is the same as the transmission coefficient (t_2) since there are no further downstream transmission losses. Thus, the total load to the receiving water in Figure 3 is 104 mt/yr. In the example worksheets all transmission (t) values are set at 1.0 for ease in demonstration.

Bio-Available Fraction (column b_7)

Column b_7 provides room for an optional entry of a factor representing the fraction of the total pollutant load from each source (both point and nonpoint) that is judged to be in a biologically available form. Biological availability is especially important to the comparison of the cost-effectiveness of control strategies, since the most desirable controls would naturally be those shown to yield the greatest reduction in the biologically available fraction of a pollutant. A further discussion of biological availability is found in Chapter 5 and Sonzogni *et al.* (1980). Naturally column b_7 would not be used when evaluating the impacts of control strategies on the total form of various pollutants (as in the example basin).

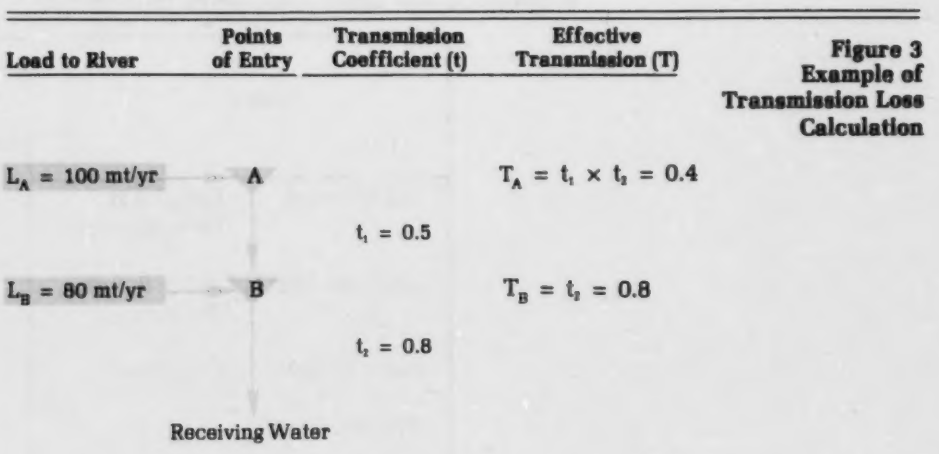


Figure 3 Example of Transmission Loss Calculation

$$L_{RW} = (L_A \times T_A) + (L_B \times T_B)$$
$$= (100 \times 0.4) + (80 \times 0.8) = 104 \text{ mt/yr}$$

where

L_A = Total Pollutant Load to Point of Entry A
L_B = Total Pollutant Load to Point of Entry B
L_{RW} = Total Pollutant Load to Receiving Water

If control strategy reduces the L_A by 50% (i.e., 50 mt/yr, then the new load (L_{RW_1}) is

$$L_{RW_1} = (50 \times 0.4) + (80 \times 0.8) = 84 \text{ mt/yr}$$
$$L_{RW} - L_{RW_1} = 104 - 84 = 20 \text{ mt/yr}$$

Therefore, a 50 mt/yr reduction to entry point A produces only a 20 mt/yr reduction at the receiving water.

Total Load to Surface Water (column c_7)

The data entered in column c_7 on Worksheet 7, "Total Load to the Surface Water," is taken directly from column a_5 on Worksheet 5 which describes the initial condition. Recall that the values in column a_5 were generated on previous worksheets to provide an estimate of the initial or uncontrolled loading to the main channel from all sources identified. This information is now simply transferred to column c_7.

Load at Mouth (column d_7)

The data in columns a_7 through c_7 are now used to calculate the values to be entered in column d_7—the annual load transmitted from each point of entry to the river mouth (ultimate receiving water). Entries in column d_7 take into account transmission losses and, if desired, the biologically available fraction of pollutant loadings at the river mouth. The portion of the river mouth load attributable to any one pollutant

Source	Position	a_7 Effective Transmission	b_7 Bio-Available Fraction	c_7 Total Load to Surface Water (kg/yr)	d_7 Load at Mouth (kg/yr)
Wolf Creek Cropland	1	1.0		21,250	21,250
Noncropland	2	1.0		2,000	2,000
Jackson Municipal, Point	3	1.0		11,100	11,100
Unsewered	4	1.0		3,750	3,750
Rock Creek Cropland	5	1.0		50,000	50,000
Middle River Cropland	6	1.0		18,750	18,750
Green Creek Cropland	7	1.0	NA	22,500	22,500
Noncropland	8	1.0		2,750	2,750
Monroe Municipal, Point	9	1.0		26,000	26,000
Separate Storm	10	1.0		6,200	6,200
Combined Sewer	11	1.0		9,000	9,000
Lower River Cropland	12	1.0		30,000	30,000
Noncropland	13	1.0		500	500
Hamilton Municipal, Point	14	1.0		26,600	26,000
Separate Storm	15	1.0		15,000	15,000
TOTAL				245,400	245,400

source is obtained by multiplying the column c_2, the total load to the surface water, by column a_7, the effective transmission, and this product is then multiplied by column b_7, the biologically available fraction (if applicable). In terms of the columns on Worksheet 7, this would mean multiplying columns $a_7 \times b_7 \times c_7$ and entering the result in column d_7. For example, if the effective transmission is 0.8 and the biologically available fraction is not applicable (which is equivalent to an assumed value of 1.0) the calculated load at the river mouth from Wolf Creek would be 0.8 × 1.0 × 21,250 kg/yr. Thus, a value of 17,000 kg/yr is entered in d_7. This same procedure is carried out for each source identified, including those which are not considered for pollution control.

Once this step is completed, the values in column d_7 are summed to provide an estimate of the total load at the mouth. This estimate should then be checked against measured river mouth loads (if available). Differences between estimated and measured loads may be due to a variety of factors (see Reckhow *et al.*, 1980 for a further discussion of these factors). Because both the estimated and measured loads are based upon the best information sources available, which have inherent uncertainties, they should not be expected to agree completely, but if they compare reasonably well the user has some assurance that the assumptions made are correct. A large discrepancy would signal the need to check the worksheets for mathematical errors, unreasonable assumptions, or unique characteristics of the sub-basins that require more detailed analysis. A further discussion on checking results is presented in Chapter 3.

Of course, if the measured river mouth load was utilized in Worksheet 4 to calculate a basinwide cropland load, the load arrived at in column d_7 and the measured load will obviously be the same. If not, mathematical errors have occurred on one or more of the worksheets. If UALs or monitored sub-basin loads were used on Worksheet 4, then the sum of all entries in column d_7 can be used as a check against the monitored river mouth load.

The load at the river mouth can be mathematically expressed by Equation 4 below:

$$\text{Pollutant load at the river mouth} = \sum_{i=1}^{N} [(L_i \times BF)\ \text{cropland} + (L_i \times BF)\ \text{rural non-cropland} + (L_i \times BF)\ \text{urban land} + (L_i \times BF)\ \text{point sources} + (L_i \times BF)\ \text{other sources}] \times T_i \qquad \textit{(Equation 4)}.$$

where:

L = total load from all sources discharging to the i^{th} point of entry ($i = 1,2, \ldots N$)

BF = Bioavailability Factor,

T_i = Effective transmission from the i^{th} point of entry to the river mouth,

N = number of points of entry.

Note that more than one sub-basin and point source may be discharging to a single point of entry. For example, the cropland load to point of entry "i" in Equation 4 may be the sum of cropland loads from several sub-basins.

Load Reduction at Mouth (column e_7)

In addition to the effect transmission losses or biologically available fractions less than 1.0 have on the load delivered to the river mouth, these factors also impact the effectiveness rating of various control programs. This can be seen by examining Figure 3. If a control program reduces the pollutant load at point (A) by 50 mt/yr (50 percent reduction), the resultant load delivery to the river mouth would not be reduced by 50 mt/yr. As the example in Figure 3 illustrates, the annual load to the river mouth would be reduced by only 20 mt/yr. In other words, a fraction of the

Source		Column ➤ Position	e_7 Load Reduction at Mouth (kg/yr)	f_7 Cost of Program ($/yr)	g_7 Cost Per Unit Removed at Mouth ($/kg)	h_7 Cost-Effective Rank
Wolf Creek	Cropland	1	8,020	16,250	2.0	4
	Noncropland	2	0	---	---	--
Jackson Municipal, Point		3	8,300	31,200	3.8	7
	Unsewered	4	0	---	---	--
Rock Creek	Cropland	5	23,000	32,500	1.4	1
Middle River	Cropland	6	9,810	16,250	1.6	2
Green Creek	Cropland	7	7,920	19,500	2.4	5
	Noncropland	8	0	---	---	--
Monroe Municipal, Point		9	20,500	60,000	2.9	6
	Separate Storm	10	1,400	187,500	133.9	10
	Combined Sewer	11	500	75,000	150.0	11
Lower River	Cropland	12	17,320	32,500	1.9	3
	Noncropland	13	0	---	---	--
Hamilton Municipal, Point		14	18,000	96,000	5.3	8
	Separate Storm	15	3,600	450,000	125.0	9
TOTAL			118,370	1,016,700		

load would never have reached the river mouth due to transmission losses, and thus the remedial program can only be credited with a 20 mt/yr reduction. As shown in Figure 3, the new load would be 84 mt/yr. If the effectiveness of a control is important at the point of entry, rather than the river mouth, then this calculation can be omitted.

To calculate the river mouth load reduction attributable to the various control strategies, the load reduction from Worksheet 5 (d_s) is multiplied by the effective transmission and biologically available fraction entered on Worksheet 7. In terms of worksheet columns, this would imply the following: columns $d_s \times a_7 \times b_7 = e_7$. If no losses occur, column e_7 is identical to column d_s.

Cost of Program (column f_7)

The cost of each control program is now entered in column f_7. These costs are obtained directly from Worksheet 6 from either column g_s (if only one control strategy is present) or columnn h_s (if the staged approach is used, as will be discussed in Chapter 5).

Cost Per Unit Removed (column g_7)

Column g_7 is used to enter the estimated cost per unit of pollutant removed at the river mouth. These values are calculated for each pollutant source identified by dividing f_7, cost of program, by e_7 load reduction at mouth. In other words, the total cost of a control strategy is divided by the pollutant reduction achieved at the river mouth. This allows all control strategies to be compared on the basis of their cost-effectiveness in reducing the pollutant load at the river mouth (dollars spent per unit load reduction at the river mouth).

Cost-Effectiveness Rank (column h_7)

The final step on Worksheet 7 is to rank in column h_7 the programs according to their cost-effectiveness values, given in column g_7. The ranking proceeds from the smallest cost per unit removed to the largest cost per unit removed. So the number one program is that which has the smallest cost per unit of pollutant removed, and is therefore the most cost-effective.

In the example worksheet, the number one program is the implementation of an education and training program that will encourage conservation tillage practices in the Rock Creek sub-basin (position 5). The estimated cost-effectiveness of the number one example program is $1.40/kg of pollutant removed at the river mouth (g_7). The program would reduce the river mouth load by an estimated 23,000 kg/yr (e_7). In instances where programs have the same cost-effectiveness value, both the load reduction at the river mouth and the total cost of the program should be examined. The program that removes the greatest amount of pollutant at the river mouth would normally be ranked ahead of others with the same cost-effectiveness value.

Worksheet 8
Summary of Programs

Sources		Column ➤		a_s	b_s	c_s	d_s	e_s
		Rank (h_r)	Stage	Load Reduction (kg/yr)	Σ Load Reduction (kg/yr)	% Reduction	Cost of Reduction ($/yr)	Σ Reduction Costs ($/yr)
Rock Creek	Cropland	1		23,000	23,000	9	32,500	32,500
Middle River	Cropland	2		9,810	32,810	13	16,250	48,750
Lower River	Cropland	3		17,320	50,130	20	32,500	81,250
Wolf Creek	Cropland	4		8,020	58,150	24	16,240	97,500
Green Creek	Cropland	5	NA	7,920	66,070	27	19,500	117,000
Monroe	Municipal Point	6		20,500	86,570	35	60,000	177,000
Jackson	Municipal Point	7		8,300	94,870	39	31,200	208,200
Hamilton	Municipal Point	8		18,000	112,870	46	96,000	304,200
Hamilton	Separate Storm	9		3,600	116,470	47	450,000	754,200
Monroe	Separate Storm	10		1,400	117,870	48	187,500	941,700
Monroe	Combined Sewer	11		500	118,370	48	75,000	1,016,700

All of the programs are arranged in their ranked order on Worksheet 8 as displayed on Worksheet 7 in column h_r. Columns are provided on Worksheet 8 for the name of the source, the cost-effectiveness ranking of the program considered for its control, and for "Stage." The latter column is used only with the advanced multi-level control program formulations, discussed in Chapter 5. Column a_s is used to display the load reductions by rank position. For example, the entry at rank position 5 would be the summation of the load reductions achieved through control of the first five sources entered on Worksheet 8. The values at any position in column b_s represent the summation of values in column a_s to that rank position in the table.

Column c_s represents the percent reduction in the total river mouth load achieved through implementation of successive programs. For example, a 27 percent reduction would be achieved if the first five programs on Worksheet 8 were implemented. The values in c_s represent the sum of the load reductions in column b_s divided by the initial condition total river mouth load (sum of column d_r).

The cost of control programs is also entered on Worksheet 8 in column d_s. These values come directly from column g_s on Worksheet 6.

Costs in column d_s are summed in e_s so that a total cost can be easily identified for the most cost-effective combination of programs. For example, the value entered in column e_s at rank position 3 reflects the sum of the costs associated with the first three positions in column d_s. This column is similar to column b_s in that it provides a running total for any particular rank position on the worksheet.

For the information on this worksheet to be effectively interpreted, the WATERSHED user must keep in mind that the program rankings are not absolute. They are based on numerous assumptions and the integration of an extensive data base. It would not be appropriate, therefore, to conclude that the rankings presented on Worksheet 8 should be used to define the exact programs which should be implemented to meet a specified waste allocation objective for the river basin under study. However, the information can be used as a method of screening programs to identify those which should be considered in more detail.

Note: A completed worksheet example using the Sandusky River basin is provided in Appendix E which includes staged control strategies and some of the more advanced features that are discussed in Chapter 5.

chapter three
interpreting and checking results

Many different data sources must be utilized to estimate point and nonpoint source pollutant loadings to a receiving water system. While information is usually available on the amounts of contaminants leaving municipal and industrial sources, it is usually quite difficult to accurately assess nonpoint source contributions, expecially considering the factors, such as bioavailability and transmission losses, that affect the amount of harmful pollutant reaching the river mouth. Because of these problems, the comparison between estimated and measured river mouth loads is one of the most important components of the WATERSHED process.

The data assembled in the appendices of this handbook provide typical estimates of pollutant loadings, control costs, and load reductions. Unit Area Loads (UALs) presented in Appendices C and D represent average annual inputs derived from a number of different river basin studies. Proper interpretation of these values is important because every river basin is different. When comparing estimated runoff loadings derived from these average values with monitored loadings, the user must be able to recognize and interpret discrepancies which may arise. The following discussion focuses on ways to account for some of the more common problems encountered in checking and interpreting WATERSHED results.

Estimating Pollutant Loadings to the Tributary

As described in Chapter 2, Worksheets 2, 3 and 4 are used to derive estimates of diffuse pollutant loadings from urban, rural noncropland, and cropland areas, respectively. As previously mentioned, the most desirable method of obtaining loading data for these sources is directly from monitoring programs. However, because empirical measurements will usually be unavailable, it is frequently necessary to use methods of approximation such as Unit Area Loads (UALs), the Universal Soil Loss Equation (USLE), or various mathematical models of nonpoint source pollution. If such methods are utilized, the following factors should be taken into consideration when checking estimated loadings against available field measurements:

1. Measured sub-basin loads may not reflect contributions from the entire sub-basin drainage area.
2. Measured sub-basin loads may reflect a high or low flow condition rather than an average annual condition.
3. Physiographic and demographic characteristics of the sub-basin may be changing at a rapid rate so that present conditions vary from those during which data was collected.
4. Available field measurements may be inaccurate or insufficient for comparison with estimated loads.
5. UALs used to estimate nonpoint source pollutant loadings may not be representative of the sub-basins under study.
6. For sub-basins where the USLE has been used on Worksheet 4, an improper assumption may have been made in selecting the transmission coefficients or delivery ratios.

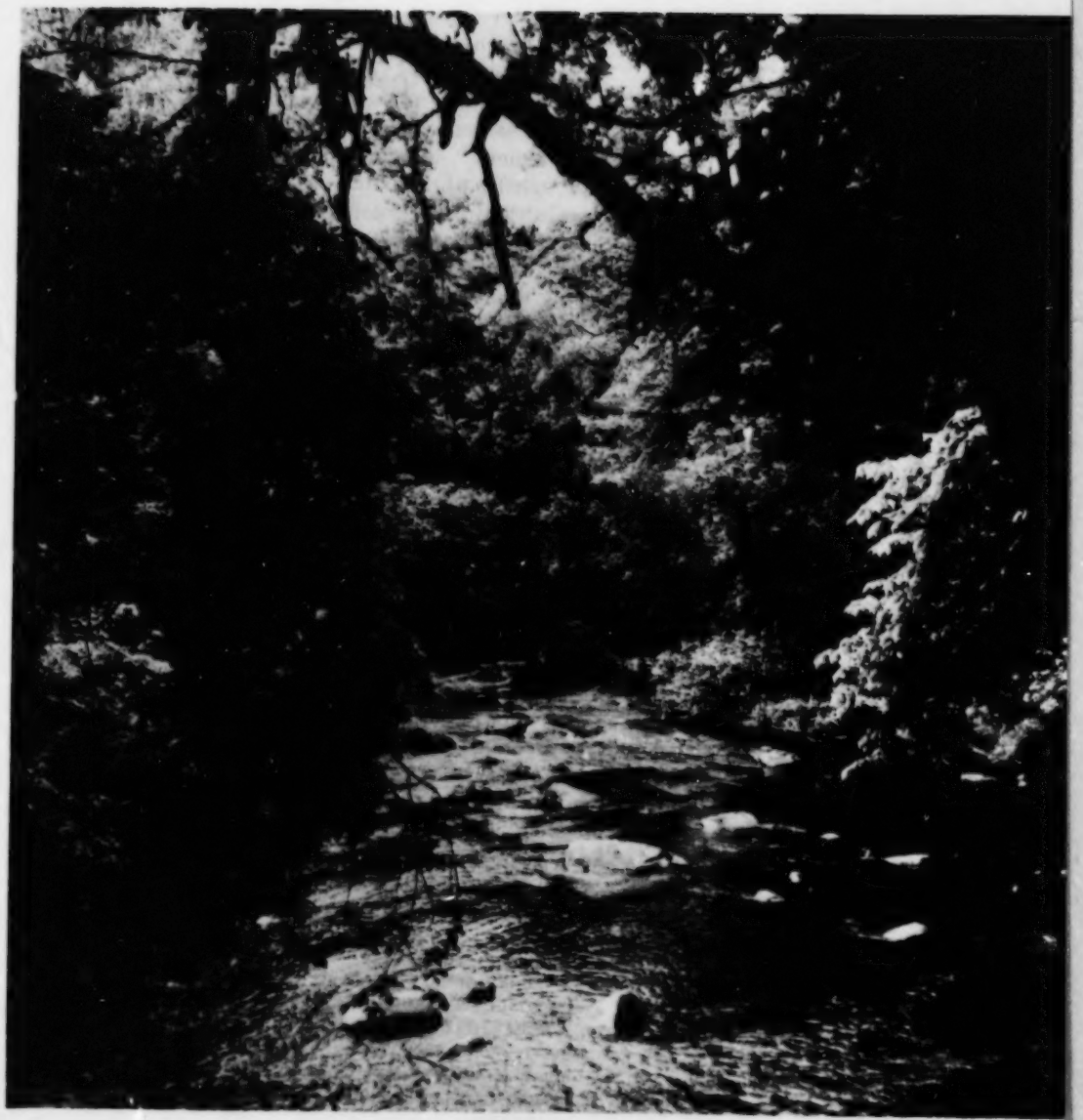
Each of the aforementioned problems can result in large discrepancies between estimated and measured loadings. No attempt has been made here to address methods of resolving these difficulties. Each is unique and requires careful evaluation by the WATERSHED user. For example, a measured cropland load obtained from sampling conducted during a

high-flow year may be adjusted to reflect present conditions by the use of a weighting factor which takes into account the ratio of the annual flow for the year of sampling to the historical average annual flow. This presupposes a known relationship or correlation between cropland load and flow within the sub-basin. Because such relationships will vary among regions, it is impossible to provide a single approach.

Estimating Pollutant Loadings to the Rivermouth

When evaluating the total pollutant load delivered to the rivermouth, a number of additional factors can account for discrepancies between estimated WATERSHED loads and loads derived from field measurements. One source of error is the assignment of an incorrect transmission coefficient to a river reach. As explained in Chapter 2, the purpose of the transmission coefficient is to account for pollutant losses between adjacent points of entry. These losses may result from phenomena such as entrapment of material within an impoundment or sedimentation along low-gradient flood plains. Because the estimated rivermouth load is sensitive to the values assigned to these coefficients, it is essential that the WATERSHED user be familiar with the physical characteristics of the system. Transmission coefficients are intended to enable the user to take into account the sensitivity of pollutant loadings and remedial measures to transmission losses. They should not be indiscriminately used to adjust the estimated rivermouth load to match a measured load.

The recommended method of accounting for transmission losses when comparing estimated and measured rivermouth loads is to initially assign a value of 1.0 (100 percent transmission) to all coefficients as was done in the Chapter 2 example (Worksheet 7). After calculating the total pollutant load at the rivermouth on Worksheet 5 (summation of values in col-



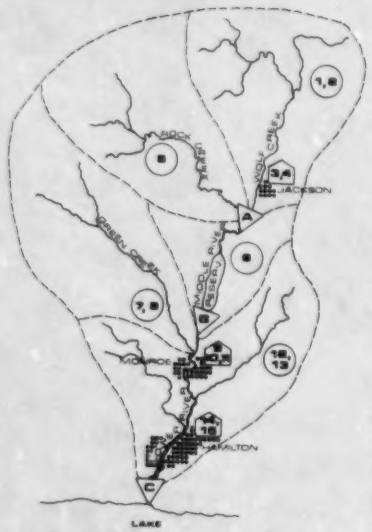


Figure 1

umn a_s), this value can be checked against a measured rivermouth load that has been adjusted to reflect average annual nonpoint source contributions. If the estimated and monitored loads are in "good agreement"[1] and careful study of the physical characteristics of the tributary system does not indicate pollutant transmission losses, the user may proceed with calculations on subsequent worksheets. This does not imply that transmission losses do not occur, only that there is insufficient evidence to conclude otherwise at this point.

In cases where the estimated total annual rivermouth load from WATERSHED is significantly greater than the measured rivermouth load (after adjusting for differences attributable to climatological factors), the user should examine hydrologic maps or layouts of the river basin system to identify physical characteristics which may result in entrapment of pollutants during transport. If one or more potential transmission loss locations are noted, the appropriate transmission coefficients should be adjusted downward to reflect the fraction of the pollutant load lost or retained in that particular section of the river.

The impact of transmission losses on the WATERSHED process can be seen by examining the sample river basin described in Chapter 2. On Worksheet 7 all of the effective transmission values were set at 1.0. For example purposes assume the estimated total load at the mouth (sum of column d_7) was high by 50,000 kg/yr compared to the measured load of 199,000 kg/yr. By examining Figure 1, it could be deduced that the reservoir between points of entry A and B may be acting as a permanent trap to the pollutant. In order to better take into account the impact of the reservoir on transmission, the effective transmission (TA) value will be set at 0.5 in this example. Pollutant sources 1 through 5 all enter at point A so each is affected by the reservoir.

Worksheet 7 is recalculated with new values in columns d_7, e_7, g_7 and h_7 (compare this example with Chapter 2, Worksheet 7). Trapping of material in the reservoir lowers the amount of pollutant delivered to the river mouth (column d_7) and the load reduction seen at the mouth with control programs in effect (column e_7). The estimated rivermouth load is now 201,350 kg/yr, much closer to the measured value of 195,000 kg/yr.

This change in the assumed effective transmission also influences the cost-effectiveness (column g_7) and the rank (column h_7). Because the cost is still the same for the control programs (column f_7) and the effectiveness at the mouth is reduced (column e_7), the cost per unit removed at the mouth (column g_7) goes up. The ranking is performed in column h_7 and the results can be compared with the Chapter 2 example where all effective transmission values were equal to 1.0.

Results of Checking Watershed Estimates Against Collected Data

The WATERSHED approach was applied in the Great Lakes Basin Commission's Great Lakes Environmental Planning Study (GLEPS) to estimate total phosphorus loadings within the entire U.S. portion of the Great Lakes basin. The estimates were compared with estimates derived from data obtained from field sampling conducted under Pollution from Land Use Activities Reference Group (PLUARG). The data, which were collected over a four year period, were adjusted to average annual conditions by flow weighting loadings (see Monteith and Sonzogni, 1981) using the long-term historical flow. This was done to

[1]The definition of "good agreement" will vary with the pollutant under study and the management objectives of the WATERSHED application. An estimated load within ± 25 percent of a measured load may be considered "good agreement" in one situation, while a discrepancy in excess of ± 5 percent may be considered poor in some other WATERSHED application.

Source	Position	Column ➤ a, Effective Transmission	a, Bio-Available Fraction	b, Total Load to Surface Water (kg/yr)	c, Load at Mouth (kg/yr)	d, Load Reduction at Mouth (kg/yr)	e, Cost of Program ($/yr)	f, Cost Per Unit Removed at Mouth ($/kg)	g, Cost-Effective Rank	h,
Wolf Creek Cropland	1	~~1.0~~	0.5	21,250	~~21,250~~ 10,625	~~8,020~~ 4,010	16,250	~~2.0~~ 4.0	~~4~~ 6	
Noncropland	2	~~1.0~~	0.5	2,000	~~2,000~~ 1,000	0	---	---	---	
Jackson Municipal, Point	3	~~1.0~~	0.5	11,100	~~11,100~~ 5,550	~~8,300~~ 4,150	31,200	~~3.8~~ 7.5	~~7~~ 8	
Unsewered	4	~~1.0~~	0.5	3,750	~~3,750~~ 1,875	0	---	---	---	
Rock Creek Cropland	5	~~1.0~~	0.5	50,000	~~50,000~~ 25,000	~~23,000~~ 11,500	32,500	~~1.4~~ 2.8	~~1~~ 4	
Middle River Cropland	6	1.0		18,750	18,750	9,810	16,250	1.6	2 1	
Green Creek Cropland	7	1.0	NA	22,500	22,500	7,920	19,500	2.4	~~5~~ 3	
Noncropland	8	1.0		2,750	2,750	0	---	---	---	
Monroe Municipal, Point	9	1.0		26,000	26,000	20,500	60,000	2.9	~~6~~ 5	
Separate Storm	10	1.0		6,200	6,200	1,400	187,500	133.9	10	
Combined Sewer	11	1.0		9,000	9,000	500	75,000	150.0	11	
Lower River Cropland	12	1.0		30,000	30,000	17,320	32,500	1.9	~~3~~ 2	
Noncropland	13	1.0		500	500	0	---	---	---	
Hamilton Municipal, Point	14	1.0		26,600	26,000	18,000	96,000	5.3	~~8~~ 7	
Separate Storm	15	1.0		15,000	15,000	3,600	450,000	125.0	9	
TOTAL				245,400	~~254,400~~ 201,350	~~118,370~~ 98,710	1,016,700			

remove bias toward particularly high or low runoff years.

Results from the WATERSHED analysis were compared to the PLUARG monitored data for each of the 31 major U.S. Great Lakes rivers. A linear regression was performed correlating the monitored data with the WATERSHED data. The results showed a correlation coefficient of 0.86. Data that were off the regression line by a "significant" (subjective value) margin usually represented streams where WATERSHED had overestimated the load to the river mouth. These were often streams which had an impoundment or other physical barrier that would likely trap upstream phosphorus inputs. Adjusting the transmission coefficients for these streams improved the correlation to a coefficient of 0.92.

In summary, two entirely different approaches were used to estimate rivermouth loads. In the first approach, the WATERSHED technique, using unit area loads to estimate nonpoint source contributions and data from effluent sampling to estimate point source loadings, predicted the annual total phosphorus load at the river mouth. In the second approach, four years of rivermouth water quality data were used to calculate a flow weighted rivermouth total phosphorus load. When rivermouth loads were compared for these two cases a good linear correlation was observed.

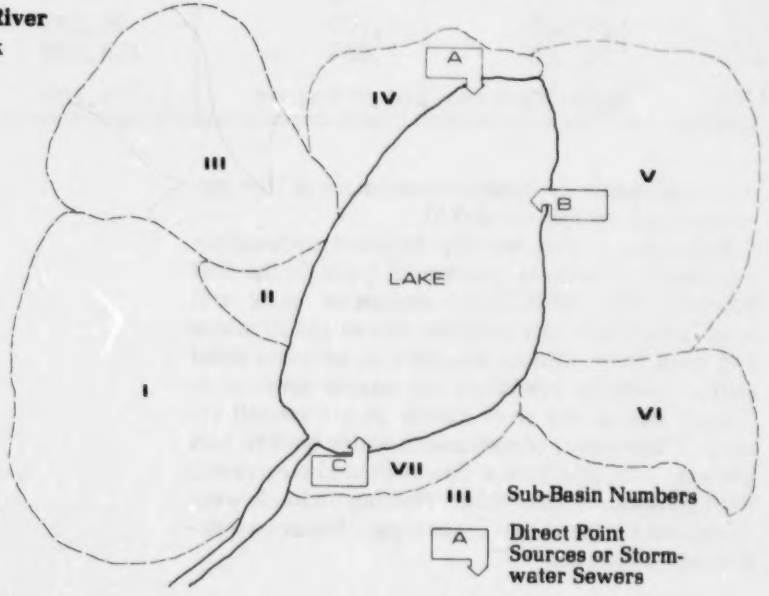
chapter four
river basin networks and load allocation

The preceding chapters have dealt with the analysis of a single river basin. Frequently a water quality manager is concerned with more than one tributary draining to a lake or estuary. The WATERSHED process is able to accommodate the analysis of multiple river basins or direct point sources. This chapter describes how multiple basins and sources may be linked and analyzed to determine which pollutant source (located within different basins) can be controlled to provide the most cost-effective load reduction to a large body of water.

As a result of legislation, some pollutant sources, such as municipal wastewater treatment plants, may already have pollution control programs in effect. For example, all plants discharging to surface waters within a river basin may be required to limit their effluent concentration of total phosphorus to 1.0 mg/L. The impact of such a requirement, compared with other forms of remedial controls, could also be evaluated using this network process.

Chapter 2 described how an individual river basin was broken down into sub-basins and how the significant sources of pollution were identified. The procedure outlined in Chapter 2 would be applied to each river basin identified in the region of interest. Figure 4 shows a hypothetical network containing several river basins feeding into a lake. For example purposes consider river basin II to be the same sample basin used in Chapter 2.

Figure 4
Hypothetical River Basin Network



Calculations on the first six worksheets should be completed for each basin identified within the network. An additional set of worksheets is used to account for point sources discharging directly to the lake. In Figure 4, three different direct point sources have been identified (labelled A through C).

The next step is to complete columns a, through g, on each river basin's Worksheet 7 and on a Worksheet 7 for all direct point sources. The cost-effectiveness rank in column h, is *not* generated at this point.

To determine the best mix of programs to reduce the load to the lake, cost-effectiveness ranking would be performed by comparing all of the cost/unit values in column g, on all Worksheets 7 (i.e., the ranking is among all programs considered for control in all the sub-basins within the river basin network).

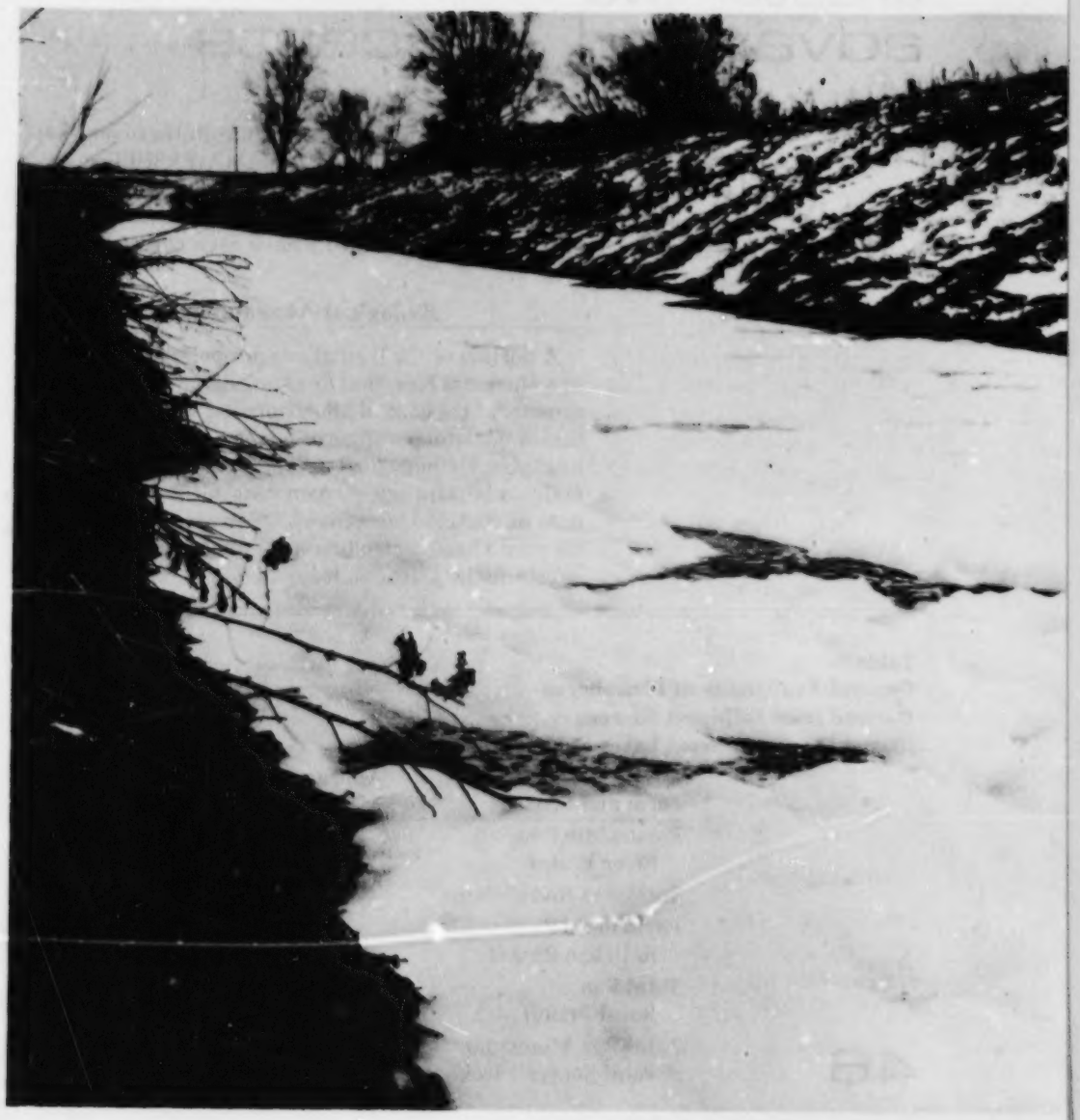
Finally, a single Worksheet 8 is prepared which accounts for all pollutant sources within all of the

different river basins and sub-basins identified. The ranking of programs over the entire network provides a comparison of their cost-effectiveness in reducing pollutant loadings to the lake.

Using Figure 4 as an example, assume that the current load of pollutant "X" to the lake is 1,460 kg/yr. The WATERSHED user wishes to formulate the most cost-effective strategy for reducing this load to 800 kg/yr—a reduction of 660 kg/yr. After the worksheets have been completed through column g, for all river basins and direct point sources, values in column g_7 are labeled in column h_7 in order of cost-effectiveness rank. This ranking would then be transferred onto a single Worksheet 8. Column b_8 represents a summation of load reduction to the lake from all river basins and direct point sources. It is then possible to select the highest ranked combination of programs which would achieve the 660 kg/yr reduction in the load of pollutant "X" delivered to the lake. By assuming the first 8 programs would achieve this objective, the procedure implies that under average conditions the desired load reduction could be met. The total cost of these programs is also found in column e_8.

The eight programs selected may be scattered throughout the lake drainage area. For instance, program No. 1 might represent a new tillage practice to be implemented in River Basin IV, program No. 5 might consist of improved settling at direct point source C, and program No. 8 might be a streetsweeping program in a city within River Basin VII.

This networking approach provides a framework for comparing all possible options for meeting a desired water quality objective. It should be stressed that this is a general initial approach to help identify those critical sources that need further investigation. More advanced techniques which can be applied to this networking system are discussed in Chapter 5.



chapter five
advanced concepts

This chapter presents several different concepts which may be added to the basic WATERSHED analysis. These "advanced concepts" offer the manager an opportunity to analyze river basins in more detail once the basic worksheets have been completed.

Biological Availability

A portion of the load of certain pollutants may be in a chemical form that does not stimulate biological growth. In the case of phosphorus, a substantial portion of the total phosphorus load may be in a form unavailable for biological uptake. Availability is especially important when comparing the cost-effectiveness of control alternatives. Otherwise, funds could be wasted on controlling a pollutant that does not substantially affect water quality.

Table 5
General Availability of Phosphorus Derived from Different Sources (Based Mostly on Great Lakes Studies)

Form and Source	Approx. % Available Phosphorus at the Point of Discharge
Particulate P in River Water	40 or less
Total P in River Water	50–60 or less
Particulate P in Urban Runoff	50 or less
Total P in Rural Runoff	50 or less
Total P in Municipal Point Source Discharges	70 or more

While information on biological availability is still incomplete, enough information does exist, particularly for phosphorus, to make some generalizations that can be applied in WATERSHED. Sonzogni *et al.* (1981) recently reviewed the existing information on phosphorus availability. Table 5 is based on their review.

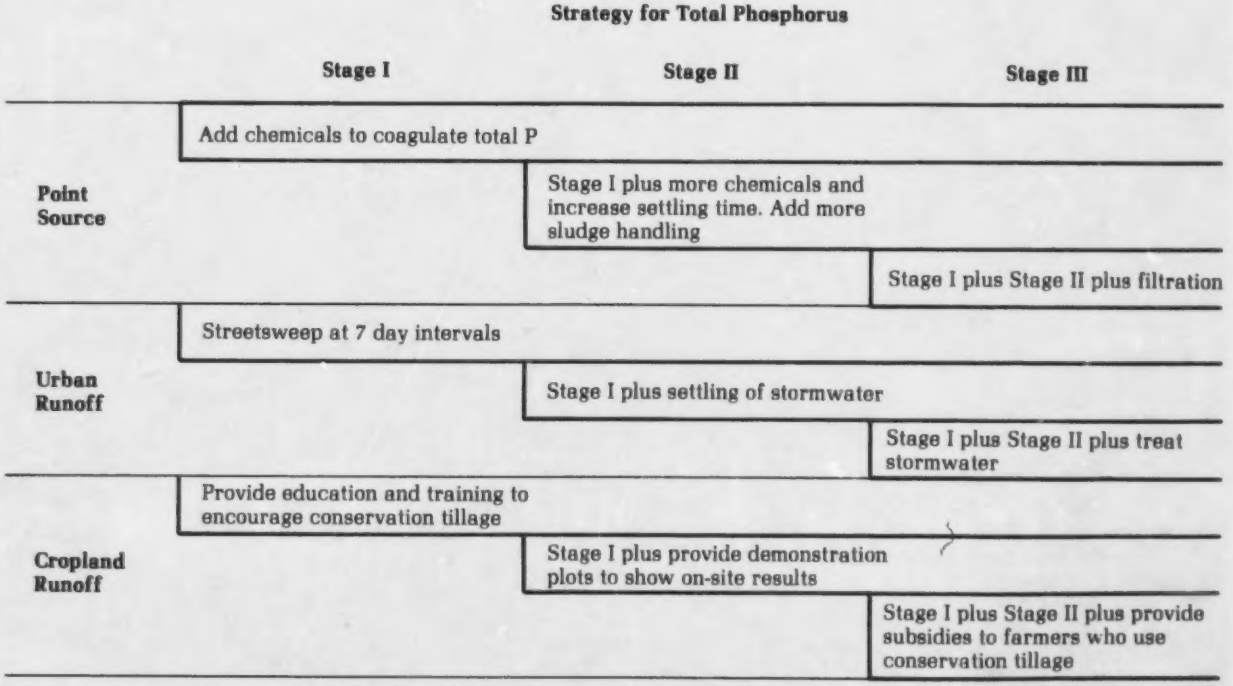
Table 5 shows that the bioavailability of phosphorus in runoff water is generally less than half of the total. In contrast, phosphorus in municipal point source discharges is largely available, at least compared to other sources at the point of discharge. Based on limited data, the type of sewage treatment or phosphorus removal practice does not appear to affect what fraction of phosphorus in the effluent is bioavailable. However, once the effluent is discharged to a stream the available phosphorus from a municipal sewage plant will bind to the stream sediments and suspended material. Thus, the available phosphorus load from a plant far upstream may be significantly reduced as a result of this action by the time it reaches the downstream receiving water (Verhoff *et al.*, 1978; Logan, 1980).

Because the bioavailability of phosphorus from point and nonpoint sources seems to differ widely, it is important that it be considered in certain cost-effectiveness analyses. In WATERSHED, the bioavailable pollutant load from a particular source is estimated by multiplying the total load from that source by the bioavailable fraction, as discussed in Chapter 2. Since the bioavailable fraction will almost never be established for an individual source, the value must be estimated. In most situations, it is advisable to work with a range of bioavailable fractions to determine the sensitivity of the analysis to this factor.

In considering bioavailability, the user must be attentive to the effects of control measures on both the bioavailable and total form of a pollutant delivered from a source. As discussed in Sonzogni *et al.* (1981), bioavailable phosphorus is not necessarily reduced in proportion to the total phosphorus load as control measures are implemented. For instance, conservation tillage may have a negligible effect on or may even increase soluble phosphorus loads. Thus, large reductions in particulate phosphorus as a result of conservation tillage could greatly reduce the total phosphorus load but have less of an effect on the bioavailable P load. For more information on this point the user is referred to Logan (1980) and Mueller *et al.* (1981).

Very little information exists on the bioavailability of parameters other than phosphorus. Limited studies on suspended solids from tributaries of the Great Lakes indicate that about 20 to 70 percent of particulate copper, zinc and lead are in an available form.

Figure 5
Example of Staged Pollution Control Strategy



The availability is likely to vary with location, size of the particle, and the specific metal. Generally, 50 percent of total particulate metals may be considered available for the analytical purposes of WATERSHED.

Staged Control Strategies

In WATERSHED a strategy to control a pollution source (rural runoff, urban runoff, and municipal point sources) may be staged; that is, it may consist of one or more incremental control programs. Incremental programs, where one program builds upon another, may be appropriate in many situations. For instance, a municipal point source control strategy for phosphorus might consist of three stages of chemical phosphorus control. Stages I, II and III might be treatment to the 1.0 mg/L, 0.5 mg/L and 0.3 mg/L phosphorus effluent levels, respectively. Stage III could not be implemented before Stage II, and Stage II could not be implemented before Stage I. However, it is possible that Stage I and II point source control programs should be implemented before either a Stage I cropland or Stage I urban runoff control program. Figure 5 shows a schematic representation of an example of a staged pollution control strategy for total phosphorus. This figure could represent a strategy for a single river basin or an entire network.

Appendix E contains a set of worksheets in which control programs are grouped into stages of implementation. Any number of stages can be formulated for a pollutant source. For this example, two stages of control were selected for each source (rural runoff, urban runoff, and municipal point sources). Total phosphorus is the pollutant to be controlled.

Note that the stages of control in Appendix E are formulated as incremental levels of treatment. Thus, the costs and load reductions presented for Stage II controls are in addition to the costs and load reductions associated with Stage I controls. In other words, for any given loading source, the ability to implement a Stage II control is dependent on implementing the Stage I control first.

A given stage of control may itself consist of several different control measures. This allows for site specific application of a general control program over a broad area, since "across-the-board" runoff control programs are more the exception than the rule. For example, to decrease the pollutant contribution from a cropland area, several different tillage practices may be used on individual farms in the area, depending on factors such as the farmer's preference, type of cropland, and the characteristics of the land. Analytically (i.e., in the WATERSHED accounting) the different control measures would be viewed in combination. An average level of pollutant reduction at an average cost would be utilized for the program.

Finally, more than one strategy, each consisting of one or more stages of control, can be proposed for a river basin. Each of these strategies should be evaluated separately using the WATERSHED process and then compared.

Application of WATERSHED to Various Pollutants

The previous discussion has focused on the application of WATERSHED to phosphorus and suspended solids loadings. With proper base information other pollutants can be analyzed using the same worksheet techniques. Available loading data for metals and other pollutants can be found in Appendices A through D. Pollutant delivery ratios and bioavailable fractions should be modified depending upon the pollutant and location.

chapter six
linear programming

The following two sections discuss a management technique known as linear programming. This technique does not follow the worksheet approach discussed throughout the rest of the handbook. While some of the worksheets may be helpful, linear programming is presented as an advanced concept with its own format requirements.

Load Allocations—Advanced Networks

If a load limitation has been imposed on a particular river basin, WATERSHED can be used to determine the most cost-effective combination of strategies to achieve the desired pollutant load. If water quality improvements are to be made in increments, WATERSHED can show which measures are most cost-effective from a water quality standpoint and should be examined first. Since control measures will have benefits and costs other than those considered in WATERSHED, the planner or manager should also take these into consideration if more detailed planning or construction is to be undertaken. For example, many nonpoint control measures improve soil conservation as well as water quality. Consequently, it may be necessary to implement some nonpoint control measures for soil conservation even though they have little effect on water quality.

The previous discussion has focused on the application of WATERSHED to phosphorus and suspended solids loadings. With proper base information other pollutants can be analyzed using the same worksheet techniques. Available loading data for metals and other pollutants can be found in Appendices A through D. Pollutant delivery ratios and bioavailable fractions should be modified depending upon the pollutant and location.

If load allocations are made among different sources to a waterbody, linear program techniques can be used. Linear programming is an optimization technique that can determine the least cost reduction in pollutant loads from different sources necessary to reach a desired overall load. Data for this approach can be compiled in Worksheets 1 through 6.

Data required to use a linear programming approach for load allocations include the present pollutant loadings for each source as well as the unit costs of reducing these loadings. Also required is the target load reduction objective for the water course being analyzed. The flexibility of linear programming also allows incorporation of additional technological, economical, political and/or social constraints (e.g., maximum or minimum allowable expenditure at a particular source, maximum or minimum load reduction required at a particular source).

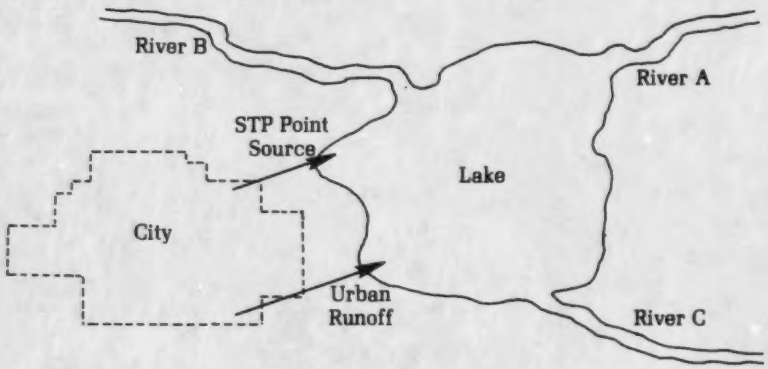
Once the linear programming objective function and constraints have been formulated, the optimum solution for simple cases can be found with the aid of a pocket calculator using the Simplex Tableau Method (Au and Stelson, 1969). For more complex cases, a computer program can be utilized. Linear programming computer software is readily available and relatively easy to use (see Hall, McWhorter, and Spivey, 1977).

An example of the application of linear programming to a hypothetical load application problem follows. Since a complete discussion of linear programming is beyond the scope of this handbook, the user is referred to the many fine texts on this subject (see Au and Stelson, 1969). In addition, examples of actual

applications of linear programming techniques to river basin management may be found in Heidtke *et al.* (1980).

Linear Programming Example 1—Load Allocations

Assume the following phosphorus loading situation in a hypothetical lake:



Source	Present P Loading (kg/yr)
River A	18,868
River B	20,816
River C	37,072
STP	28,200
Urban Runoff	12,650
Total	117,606

It is desired to reduce the total phosphorus loading to the lake by 70,000 kg/yr. Therefore,

$$L_T = \text{target load reduction} = 117{,}606 - 70{,}000 = 47{,}606 \text{ kg/yr.}$$

The unit costs for reducing phosphorus loads at the lake for each of the sources are known to be:

Source	Unit Cost of P Removal ($/kg reduced at the lake)
River A	1.2
River B	1.0
River C	0.8
STP	2.2
Urban Runoff	123.3

Objective Function. The objective of the analysis will be to achieve the required loading reduction at the minimum annual cost:

$$\text{Min } C_T = \sum_i L_i C_i$$

where:

C_T = total annual cost of reductions ($/yr)

L_i = required reduction in phosphorus loading from source i (kg/yr)

C_i = unit cost of phosphorus reduction at source i ($/kg)

Therefore, the objective function for this case is:

$$\text{min } C_T = 1.2L_A + 1.0L_B + 0.8L_C + 2.2L_{STP} + 123.3L_{UR}$$

Constraints.

1. The first constraint will state that the sum of the phosphorus load reductions at each source must achieve the target load reduction. In general:

$$\sum_i L_i \geq L_T$$

Therefore, in this case:

$$L_A + L_B + L_C + L_{STP} + L_{UR} \geq 47{,}606$$

2. The next set of constraints will reflect the physical constraint that load reductions at each source cannot be greater than the present loading there:

$$L_i\text{'s} \leq L_{i\,max}\text{'s}$$

where:

$L_{i\,max}$ = present phosphorus at source i, in kg/yr.

Note that these maximum load reductions could have been set at any loading less than the present loading if required due to technological, economical, social and/or political considerations. Therefore:

$$L_A \leq 18{,}868$$
$$L_B \leq 20{,}816$$
$$L_C \leq 37{,}072$$
$$L_{STP} \leq 28{,}200$$
$$L_{UR} \leq 12{,}650$$

3. The next set of constraints will state that the load reductions at each source must be nonnegative (i.e., there can be no increase in the loading from any source):

$$L_i\text{'s} \geq 0$$

Therefore:

$$L_A \geq 0$$
$$L_B \geq 0$$
$$L_C \geq 0$$
$$L_{STP} \geq 0$$
$$L_{UR} \geq 0$$

This completes the set of constraint equations for this case. As discussed earlier other constraints, such as cost constraints reflecting maximum or minimum expenditures for load reductions or load constraints reflecting maximum or minimum reductions required at particular sources, could also have been imposed on the analysis. For example, a fixed maximum expenditure could be set for nonpoint source controls, or a load reduction limit could be set on point sources (i.e., the minimum total phosphorus concentrations of the point source effluent could be fixed at 1.0 mg/L). In summary, the complete problem statement is as follows:

$$\min C_T = 1.2L_A + 1.0L_B + 0.8L_C + 2.2L_{STP} + 123.3L_{UR}$$

subject to:

$$L_A + L_B + L_C + L_{STP} + L_{UR} \geq 47{,}606$$
$$L_A \leq 18{,}868$$
$$L_B \leq 20{,}816$$
$$L_C \leq 37{,}072$$
$$L_{STP} \leq 28{,}200$$
$$L_{UR} \leq 12{,}650$$
$$L_A, L_B, L_C, L_{STP}, L_{UR} \geq 0$$

This problem can now be solved by hand or with the aid of a computer to yield the following optimum load reductions at each source:

L_A = load reduction required in River A = 0
L_B = load reduction required in River B = 10,534 kg/yr
L_C = load reduction required in River C = 37,072 kg/yr
L_{STP} = load reduction required for the STP = 0
L_{UR} = load reduction required for urban runoff = 0

The total minimized cost of these reductions (C_T) is $40,191.60/yr. Note that this solution is exactly what would be expected for this simple case, considering the given unit costs of phosphorus reduction at each source. River C has the lowest unit cost of phosphorus reduction ($0.80/kg) and therefore, it is desirable to decrease loading from this source as much as possible (i.e., $L_{C\,max}$ = 37,072 kg/yr). The additional 10,534 kg/yr reduction required to meet the target load reduction objective of 47,606 kg/yr is then removed from River B since this source has the next lowest unit cost of phosphorus reduction (1.0/kg) and the 10,534 kg/yr reduction does not exceed its maximum obtainable reduction of 20,816 kg/yr. In more complicated cases the solution may not be as obvious.

Multiobjective Analysis

Previous chapters in this handbook have considered only one pollutant at a time. However, control strategies may affect more than one pollutant. For example, removing phosphorus at a municipal wastewater treatment plant may concurrently reduce biochemical oxygen demand, suspended solids, toxic metals, and viruses. Ideally, a multiobjective analysis should be performed so that the cost of the total phosphorus control program can be evaluated against benefits (or costs) other than just those associated with phosphorus reductions. Simon (1980) has made an initial attempt at this by modifying the overview modeling approach of PLUARG with a parametric nonlinear optimization technique.

The linear program approach discussed previously as a load allocation tool is also well-suited for multiobjective analysis. The following example illustrates it use in a hypothetical situation. For a more advanced approach, using parametric nonlinear optimization techniques, see Simon (1980).

Linear Programming Example 2— Multiobjective Analysis

Assume the following pollutant loading for a hypothetical lake:

The unit costs for reducing these three pollutants at each source are:

	Present Pollutant Loadings			Unit Costs for Pollutant Reductions		
Source	BOD (kg/yr)	Phosphorus (kg/yr)	Fecal Coliforms (10^6 cells/yr)	BOD ($/kg)	Phosphorus ($/kg)	Fecal Coliforms ($/$10^6$ cells/yr)
River 1	8,000	15,000	1.0	10	13	10
River 2	5,000	10,000	0.1	11	15	10
River 3	10,000	5,000	100	9	17	8
STP (4)	15,000	10,000	100	12	18	5
Totals	38,000	40,000	201.1			

Assume the target *load reductions* are as follows:

L_{TBOD} = target load reduction for BOD = 10,000 kg/yr.
L_{TP} = target load reduction for phosphorus = 10,000 kg/yr.
L_{TFC} = target load reduction for fecal coliforms = 100 × 10^6 cells/yr.

In order to illustrate the adaptability of linear programming to unique constraints or requirements, it will also be assumed that the money spent for reducing the pollutant loadings from nonpoint sources (i.e., the rivers) may not exceed some maximum amount:

$C_{NP\,max}$ = maximum allowable expenditure for reducing pollutants from nonpoint sources = \$15,000/yr.

Objective Function. The objective of this analysis is to achieve the required pollutant load reductions at the minimum annual cost:

$$\min C_T = \sum_j \left(\sum_i L_{i,j} C_{ij}\right) = \sum_i \left(\sum_j L_{i,j}, C_{ij}\right)$$

where:

C_T = total annual costs of reductions (\$/yr)

$L_{i,j}$ = required load reduction of pollutant i from source j (units/yr)

$C_{i,j}$ = unit cost of pollutant reduction for pollutant i from source j (\$/unit)

Therefore, the objective function for this case can be written:

$$\begin{aligned}\min C_T = {} & (10\,L_{BOD,1} + 13\,L_{P,1} + 10\,L_{FC,1}) \\ & + (11\,L_{BOD,2} + 15\,L_{P,2} + 10\,L_{FC,2}) \\ & + (9\,L_{BOD,3} + 17\,L_{P,3} + 8\,L_{FC,3}) \\ & + (12\,L_{BOD,4} + 18\,L_{P,4} + 5\,L_{PC,4})\end{aligned}$$

Constraints.

1. The first set of constraints reflects the target load reduction requirements for each of the pollutants:

$$\sum_j L_{BOD,j} \geq L_{TBOD}$$

$$\sum_j L_{P,j} \geq L_{TP}$$

$$\sum_j L_{FC,j} \geq L_{TFC}$$

so for this case:

$$\begin{aligned}L_{BOD,1} + L_{BOD,2} + L_{BOD,3} + L_{BOD,4} &\geq 10{,}000 \\ L_{P,1} + L_{P,2} + L_{P,3} + L_{P,4} &\geq 10{,}000 \\ L_{FC,1} + L_{FC,2} + L_{FC,3} + L_{FC,4} &\geq 100\end{aligned}$$

2. The next set of constraints reflects the maximum load reductions of each pollutant that can be achieved at each source. For simplicity it will be assumed that all loadings can be reduced to zero (i.e., the maximum load reduction attainable is equal to the present loading). In reality this probably would not be the case. Thus:

$$L_{i,j's} \leq L_{i,j\,max's}$$

where:

$L_{i,j\,max}$ = Maximum obtainable load reduction of pollutant i from source j (units/yr)

Therefore:

$$\begin{aligned}L_{BOD,1} &\leq 8{,}000 & L_{P,1} &\leq 15{,}000 & L_{FC,1} &\leq 1.0 \\ L_{BOD,2} &\leq 5{,}000 & L_{P,2} &\leq 10{,}000 & L_{FC,2} &\leq 0.1 \\ L_{BOD,3} &\leq 10{,}000 & L_{P,3} &\leq 5{,}000 & L_{FC,3} &\leq 100 \\ L_{BOD,4} &\leq 15{,}000 & L_{P,4} &\leq 10{,}000 & L_{FC,4} &\leq 100\end{aligned}$$

3. The next constraint represents the imposed expenditure ceiling for controlling pollutant loadings from nonpoint sources:

$$\sum_{j=1}^{3} \left(\sum_i L_{i,j} C_{i,j}\right) \leq C_{NP_{max}}$$

or:

$$\begin{aligned}& (10\,L_{BOD,1} + 13\,L_{P,1} + 10\,L_{FC,1}) \\ & + (11\,L_{BOD,2} + 15\,L_{P,2} + 10\,L_{FC,2}) \\ & + (9\,L_{BOD,3} + 17\,L_{P,3} + 8\,L_{FC,3}) \leq 15{,}000\end{aligned}$$

4. The nonnegativity constraints complete the problem statement:

$L_{i,j}$'s ≥ 0

Therefore:

$$L_{BOD,1} \geq 0 \quad L_{P,1} \geq 0 \quad L_{FC,1} \geq 0$$
$$L_{BOD,2} \geq 0 \quad L_{P,2} \geq 0 \quad L_{FC,2} \geq 0$$
$$L_{BOD,3} \geq 0 \quad L_{P,3} \geq 0 \quad L_{FC,3} \geq 0$$
$$L_{BOD,4} \geq 0 \quad L_{P,4} \geq 0 \quad L_{FC,4} \geq 0$$

Again, other constraints unique to a specific case could have been included in the above analysis.

The complete problem statement is given below:

$$\min C_T = 10\,L_{BOD,1} + 13\,L_{P,1} + 10\,L_{FC,1} + 11\,L_{BOD,2} + 15\,L_{P,2} + 10\,L_{FC,2} + 9\,L_{BOD,3} + 17\,L_{P,3} + 8\,L_{FC,3} + 12\,L_{BOD,4} + 18\,L_{P,4} + 5\,L_{FC,4}$$

subject to:

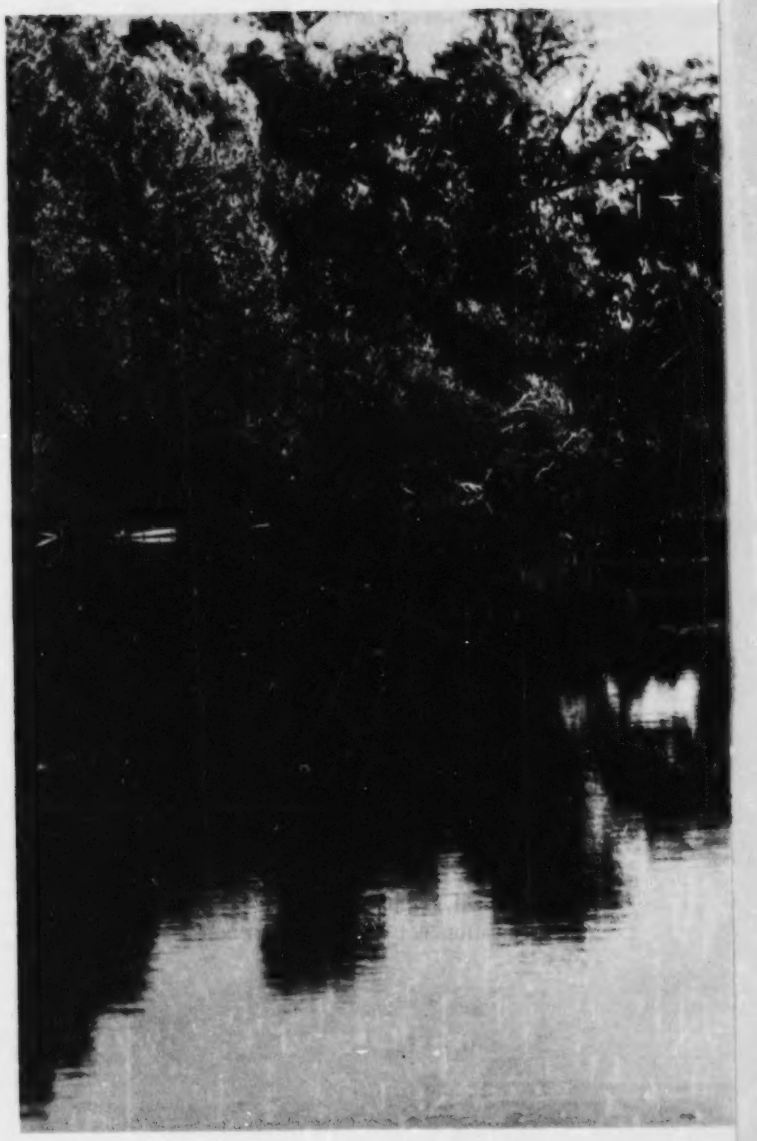
$$L_{BOD,1} + L_{BOD,2} + L_{BOD,3} + L_{BOD,4} \geq 10{,}000$$
$$L_{P,1} + L_{P,2} + L_{P,3} + L_{P,4} \geq 10{,}000$$
$$L_{FC,1} + L_{FC,2} + L_{FC,3} + L_{FC,4} \geq 100$$

$$L_{BOD,1} \leq 8{,}000 \quad L_{P,1} \leq 15{,}000 \quad L_{FC,1} \leq 1.0$$
$$L_{BOD,2} \leq 5{,}000 \quad L_{P,2} \leq 10{,}000 \quad L_{FC,2} \leq 0.1$$
$$L_{BOD,3} \leq 10{,}000 \quad L_{P,3} \leq 5{,}000 \quad L_{FC,3} \leq 100$$
$$L_{BOD,4} \leq 15{,}000 \quad L_{P,4} \leq 10{,}000 \quad L_{FC,4} \leq 100$$

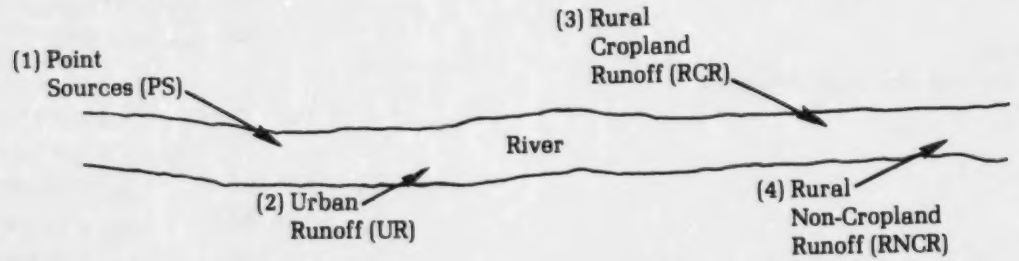
$$10\,L_{BOD,1} + 13L_{P,1} + 10\,L_{FC,1} + 11\,L_{BOD,2} + 15\,L_{P,2} + 10\,L_{FC,2} + 9\,L_{BOD,3} + 17\,L_{P,3} + 8\,L_{FC,3} \leq 15{,}000$$

$$L_{BOD,1}, L_{BOD,2}, L_{BOD,3}, L_{BOD,4}, L_{P,1}, L_{P,2}, L_{P,3}, L_{P,4}, L_{FC,1}, L_{FC,2}, L_{FC,3}, L_{FC,4} \geq 0$$

The optimum solution would be determined with the aid of an appropriate computer program for optimization problems.



Finally, a slightly different application of linear programming is illustrated. Here the major types of pollutant sources contributing to a surface water (in this case a river) are considered as opposed to the previous two examples where individual sources were considered. In this example an upper limit on removal of pollutants (other than 100 percent, as was assumed in the first two examples) will be imposed on each pollutant source. Assume the following river basin with four major types of pollutant sources:



	BOD		Phosphorus		Unit Costs for Pollutant Reductions	
Sources	Present Loading (kg/yr)	Maximum Feasible Reduction (kg/yr)	Present Loading (kg/yr)	Maximum Feasible Reduction (kg/yr)	BOD ($/kg)	Phosphorus ($/kg)
(1) PS	20,000	19,000	15,000	14,500	120	180
(2) UR	20,000	16,000	18.000	12,000	150	160
(3) RCR	10,000	8,000	30,000	22,500	100	90
(4) RNCR	1,000	200	1,000	200	300	200
Totals	51,000	43,200	64,000	49,200		

The target load reduction objectives for the river are:

L_{TBOD} = target load reduction for BOD = 18,000 kg/yr

L_{TP} = target load reduction for phosphorus = 15,000 kg/yr

Objective Function. The objective function is formulated exactly as in the preceding example:

$$\min C_T = \sum_i \left(\sum_i L_{i,j} C_{ij}\right)$$

In this case:

$$\begin{aligned}\min C_T = {} & (120\, L_{BOD,1} + 180\, L_{LP,1}) \\ & + (150\, L_{BOD,2} + 160\, L_{P,2}) \\ & + (100\, L_{BOD,3} + 90\, L_{P,3}) \\ & + (300\, L_{BOD,4} + 200\, L_{P,4})\end{aligned}$$

Constraints.

1. Target load reduction objectives:

$$\sum_j L_{BOD,j} \geq L_{TBOD}$$

$$\sum_j L_{P,j} \geqslant L_{TP}$$

so:

$$\begin{aligned} L_{BOD,1} + L_{BOD,2} + L_{BOD,3} + L_{BOD,4} &\geqslant 18{,}000 \\ L_{P,1} + L_{P,2} + L_{P,3} + L_{P,4} &\geqslant 15{,}000 \end{aligned}$$

2. Maximum feasible reductions attainable for each source:

$$L_{i,j}\text{'s} \leqslant L_{i,j\,\max}\text{'s}$$

Remembering that for this example the maximum feasible reductions at each source are less than the present loading:

$$\begin{aligned} L_{BOD,1} &\leqslant 19{,}000 & L_{P,1} &\leqslant 14{,}500 \\ L_{BOD,2} &\leqslant 16{,}000 & L_{P,2} &\leqslant 12{,}000 \\ L_{BOD,3} &\leqslant 8{,}000 & L_{P,3} &\leqslant 22{,}500 \\ L_{BOD,4} &\leqslant 200 & L_{P,4} &\leqslant 200 \end{aligned}$$

3. Nonnegativity constraints:

$$L_{i,j}\text{'s} \geqslant 0$$

Therefore:

$$\begin{aligned} L_{BOD,1} &\geqslant 0 & L_{P,1} &\geqslant 0 \\ L_{BOD,2} &\geqslant 0 & L_{P,2} &\geqslant 0 \\ L_{BOD,3} &\geqslant 0 & L_{P,3} &\geqslant 0 \\ L_{BOD,4} &\geqslant 0 & L_{P,4} &\geqslant 0 \end{aligned}$$

In summary:

$$\begin{aligned}\min C_T = {} & 120 L_{BOD,1} + 180\, L_{P,1} + 150\, L_{BOD,2} \\ & + 160\, L_{P,2} + 100\, L_{BOD,3} + 90\, L_{P,3} \\ & + 300\, L_{BOD,4} + 200\, L_{P,4}\end{aligned}$$

subject to:

$$\begin{aligned} L_{BOD,1} + L_{BOD,2} + L_{BOD,3} + L_{BOD,4} &\geqslant 18{,}000 \\ L_{P,1} + L_{P,2} + L_{P,3} + L_{P,4} &\geqslant 15{,}000 \\ L_{BOD,1} &\leqslant 19{,}000 & L_{P,1} &\leqslant 14{,}500 \\ L_{BOD,2} &\leqslant 16{,}000 & L_{P,2} &\leqslant 12{,}000 \\ L_{BOD,3} &\leqslant 8{,}000 & L_{P,3} &\leqslant 22{,}500 \\ L_{BOD,4} &\leqslant 200 & L_{P,4} &\leqslant 200 \end{aligned}$$

$$L_{BOD,1}, L_{BOD,2}, L_{BOD,3}, L_{BOD,4}, L_{P,1}, L_{P,2}, L_{P,3}, L_{P,4}, \geqslant 0$$

A computer could now be used to solve for the optimum solution. In this case the optimum solution would be the BOD and phosphorus load reductions required for point sources, urban runoff sources, rural cropland runoff sources and rural non-cropland runoff sources in order to meet the target load reductions for the two pollutants at the minimum cost.

In the last two examples, the unit costs for reducing each of the pollutants considered were assumed to be completely independent. In other words, reduction of one pollutant has no effect on the unit cost for reducing the other pollutants. Again, this may not be the case, as the removal of one pollutant may have an effect on the removal and cost of removal of other pollutants present.

chapter seven
accounting aids

Because WATERSHED is based upon many user assumptions which carry through the entire process, it is often desirable to change an early assumption to determine its impact on the final results. This type of change can result in many additional calculations. While the mathematics involved are simple, the number of operations involved may best be handled on a programmable calculator or a computer. WATERSHED is primarily designed to be performed without these aids, however some users may wish to take advantage of the technology available to them.

Programmable Calculator

The worksheets involve many repetitive operations that are ideally suited for electronic calculators, particularly those that accept simple programs. All the equations necessary for performing the worksheet calculations are given on the bottom of the worksheet or in the text in Chapter 2. These equations may be easily programmed into any of the programmable calculators available today.

Some of the more advanced hand-held or desk top calculators will support the entire WATERSHED process. These devices are able to store the equations and the data entered for all of the worksheets, thus providing a significant time-savings once the programs have been written.

Fortran Program

For users with access to a computer, a Fortran Program is available which will perform the complete WATERSHED process. Data entry, calculations, worksheet printouts and data storage for individual river basins or up to seven basins in a network are all handled by the program. The program listings and operators manual are found in Appendix G which is a separate document from the Handbook. A tape or other user assistance can be obtained from Dr. William Sonzogni at the Great Lakes Environmental Research Laboratory, National Oceanographic and Atmospheric Administration, Ann Arbor, Michigan [phone: (313)668-2249].

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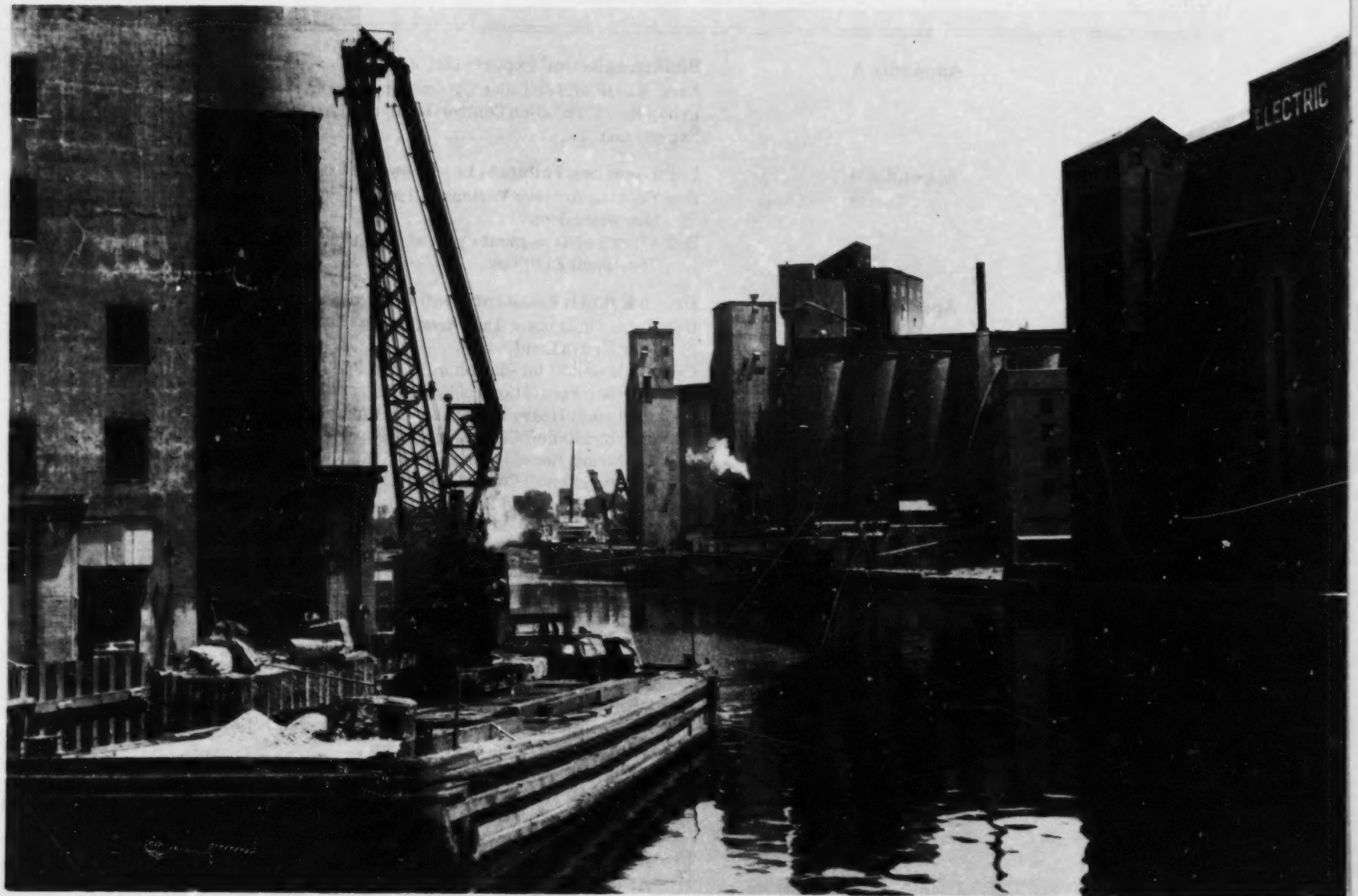
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Appendix B
Point Sources: Pollutant Loadings and Controls

Municipal Point Source Controls

Table B-1
Costs to Achieve Various Effluent Phosphorus Concentrations

Effluent Total Phosphorus Concentration (mg/L	Annual Cost ($/Capital)[1]		
	Capital[2]	O & M[3]	Total
4.0	12.15	6.25	18.40
1.0	12.70	8.18	20.88
0.5	13.12	8.85	21.97
0.3	17.93	10.74	28.67
0.1	17.52	33.23	50.75

SOURCE: Drynan, W.R. (1978). "Relative Costs of Achieving Various Levels of Phosphorous Control at Municipal Wastewater Treatment Plants in the Great Lakes," International Joint Commission, Windsor, Ontario. Based on a computer simulation model.

[1]Costs assume primary or secondary treatment exists. Costs shown are in 1980 dollars, assuming that original dollar figures were for 1978.

[2]Simulated capital costs to build and expand plant as required over a 25-year period. The per capita cost is the total simulated capital costs divided by the present population served, and the annual per capita cost (R) is the amount needed at an interest rate of 10 percent (i) to recover the investment (P) in 25 years (n).

$$R = P \frac{i}{1 - (1+i)} - n$$

[3]The operating and maintenance costs are the total O & M costs simulated for the first 5 years and divided by the present population served on an annual basis.

Table B-2
Chemical Phosphorus Treatment Costs at Municipal Wastewater Treatment Facilities

Total Cost ($/capita/yr)	Plant Sizes Represented in Sample (mgd)	P Content of Influent (mg/L)	P Content of Effluent (mg/L)	Capital and O & M Costs for		
				Chemical Treatment	Sludge Handling	Sludge Disposal
4.01[a]	1.4-17.5	—	1.0	yes	yes	yes
2.48[b]	1	10	—	yes	yes	no
1.51[b]	10	10	—	yes	yes	no
4.31[c]	1	10	—	yes	yes	no
4.20[d]	5	10	—	yes	yes	no
3.65[e]	1	10	—	yes	yes	no
3.47[f]	5	10	—	yes	yes	no
2.35[g]	6-950	—	—	yes	yes	yes

NOTE: — means information is not reported.

[a]Total cost is the population-weighted average of 1976 costs at four Michigan municipal wastewater treatment plants.

[b]Total cost does not include costs for final sludge disposal because they were considered to be variable based on local conditions and to be low relative to other cost items.

[c]Plants used different chemical additives as follows: [c]alum; [d]alum; [e]ferric chloride; [f]ferric chloride. Total costs do not include costs for final sludge disposal because of the sensitivity of those costs to location and disposal methods.

[g]Total cost was determined in a computer modeling study of 43 municipal wastewater treatment plants in the Great Lakes basin, covering a cross section of the United States and Canada.

[a] Source: Michigan Department of Natural Resources (MDNR) (1979). "Consideration of Municipal Wastewater Treatment for Phosphorus Removal in the Evaluation of a Detergent Phosphorus Ban," staff worksheets.

[b] Source: Baret, et al. (1977). "A Comparative Assessment of the Effectiveness and Cost of Different Measures Aimed at Reducing the Environmental Impact of Phosphorus in the Surface Waters of Western Europe," Battelle, Geneva Research Centre.

[c-f] Source: Ciecka, Fabian, Merilatt and Murphy (1978). "An Economic Analysis of Phosphorus Control and Other Aspects of R76-1," contracted for by Institute for Environmental Quality, State of Illinois.

[g] Source: Dryan, W.R. (1978). "Relative Costs of Achieving Various Levels of Phosphorus Control at Municipal Treatment Plants in the Great Lakes Basin," prepared for the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG), International Joint Commission (IJC), Windsor, Ontario.

Appendix C
Urban Runoff: Pollutant Loadings and Controls

Table C-1
Total Phosphorus Unit Area Loads from Urban Land

Urban Land Classification	Total Phosphorus UAL (kg/km²/yr)		
	Degree of Industrialization		
	Low	Medium	High
Combined Sewered Areas	900	1,000	1,100
Separate Sewered Areas	125	250	300
Unsewered Areas	125	—	—
Small Urban Areas (Sewer system not differentiated)	250	250	250
Urbanizing Land (Areas under construction)	2,500	2,500	2,500

SOURCE: Pollution from Land Use Activities Reference Group (PLUARG) (1978). "Environmental Management Strategy for the Great Lakes System," International Joint Commission, Windsor, Ontario.

Table C-2
Costs and Total Phosphorus Load Reductions of Urban Runoff Control Programs

Control Program	Urban Diffuse Sources							
	Combined Sewered Areas		Separate Sewered Areas					
			High Industry		Medium Industry		Low Industry	
	% UAL Reduction	$/km²/yr	% UAL Reduction	$/km²/yr	% UAL Reduction	$/km²/yr	% UAL Reduction	$/km²/yr
Streetsweeping plus Measures to Reduce Flow	0	7,400	20	7,400	25	7,400	50	7,400
Streetsweeping plus Detention/Sedimentation of Stormwater and Combined Sewer Overflows	30	32,100	40	16,000	45	16,000	65	16,000

SOURCE: Adapted from Johnson, M.G., Comeau, J.C., Heidtke, T.M., Sonzogni, W.C. and B.W. Stahlbaum (1978). "Management Information Base and Overview Modelling," prepared for the Pollution from Land Use Activities Reference Group (PLUARG), International Joint Commission, Windsor, Ontario. It is unknown what year the dollar figures represent.

Table C-3
Costs[1] and Heavy Metals Load Reductions of Urban Runoff Control Programs

Control Program	Combined Sewered Areas									Separate Sewered Areas								
	High Industry				Medium Industry				Low Industry				High Industry				Medium Industry				Low Industry			
	% UAL Reduction				% UAL Reduction				% UAL Reduction				% UAL Reduction				% UAL Reduction				% UAL Reduction			
	Zn	Cu	Pb	$/km²/yr	Zn	Cu	Pb	$/km²/yr	Zn	Cu	Pb	$/km²/yr	Zn	Cu	Pb	$/km²/yr	Zn	Cu	Pb	$/km²/yr	Zn	Cu	Pb	$/km²/yr
Streetsweeping with vacuum sweepers at 7-day intervals	38	30	41	7,400	38	30	41	7,400	38	30	41	7,400	42	42	42	7,400	42	42	42	7,400	42	42	42	7,400
Streetsweeping plus Detention/Sedimentation of Stormwater and Combined Sewer Overflows	58	52	60	32,100	58	52	60	32,100	58	52	60	32,100	61	61	61	16,000	61	61	61	16,000	61	61	61	16,000

[1]It is unknown what year the dollar figures represent.

SOURCE: Johnson, M.G., Comeau, J.C., Heidtke, T.M., Sonzogni, W.C. and B.W. Stahlbaum (1978). "Management Information Base and Overview Modelling," prepared for the Pollution from Land Use Activities Reference Group (PLUARG), International Joint Commission, Windsor, Ontario.

Table C-4
Problems, Benefits, and Costs of Urban Runoff Control Measures

Control Measure	Problems/Benefits	Cost
Chemical Soil Stabilizers	Costly; may reduce infiltration. Easy, and quick to use on disturbed areas.	$.30-1.20/m²
Dutch Drain	Due to clogging problems it must be replaced every 5-10 years. Enhances groundwater supply	$.04/L stored $18/cmm trench
Grass Channels or Waterways	Require careful design & maintenance. Increase infiltration; aesthetically pleasing.	sod: $1.20/m² seeding without topsoil but with fertilizer: $2,000/ hectare
Horizontal Shaft Screen		$170-180/L/sec O & M: .01/1000 L
Permanent Diversions	Require careful maintenance.	$21-50/m
Pits, Gravity Shafts, Trenches, Tile Fields	Problems with clogging, therefore replacement often required.	seepage pit: $20/m³ storage
Precast Concrete Lattice Blocks & Bricks	Expensive to lay; permeability not as good as asphalt.	$11.40/m²
Retention Basins	Not necessarily cost-effective; highly dependent on local hydrology & effluent requirements.	$50/m³ capacity
Roof Top Ponding	Construction problems; limited usefulness.	$80-130 each
Seepage Pits or Drv Wells	Need to be very large; require periodic replacement due to clogging	$15-19/m³ of pit or $30-40/m³ of water stored
Seepage or Recharge Basin	Have only a single use; safety hazard; require constant maintenance.	$10-20/m³ recharge capacity
Stationary Screens	Collection of sludge required; pumping may be required. Otherwise they are energy efficient.	$250/L/sec
Treatment Lagoons	Large land requirement; mosquito and odor problems.	$200-700/L/sec (excluding land costs) O & M: $2.50-3.50/1000m³
Vertical Shaft Screen	Requires a lot of space; provides good removal; high costs with low flows.	$180/L/sec O & M: $.01/1000 L

NOTES:
Because of the many factors involved in the large scale construction of detention basins, data presented here necessarily vary widely from city to city. It is apparent that larger basins can be very effective in removal of pollutants. However, the costs involved may be prohibitive.

SOURCE: Unknown. It is not known what year the dollar figures represent, but likely the early to mid-1970s.

Table C-5
Annual Costs[a] and Percent Removal of Total Suspended Solids and Biochemical Oxygen Demand, Using Detention Basins

Runoff (in/acre)	Storage Size (gal/acre)	Capital Cost[b] ($/acre)	Annual O & M[c] Cost ($/acre)	TSS UAL Reduction (%)	BOD UAL Reduction (%)
0.1	2,700	26.20	43.26	20	10
0.5	13,600	87.25	37.08	40	25
1.0	27,200	123.61	37.08	60	30
1.5	40,700	174.51	37.08	70	35
5.0	136,000	523.53	30.90	75	40

SOURCE: Stanley Consultants (1976). "Urban Intermittent Point and Nonpoint Source Control Alternatives and Cost Information—State-of-the-Art Studies, 208 Water Quality Management Planning Program.

[a]Costs in 1980 dollars. Capital costs averaged over 25-year life of project.

[b]Based on earthen structure with pipe outlet. Concrete basins or tanks will cost about four times this amount. Valid for basins serving 50 acres or less.

[c]Cost is more for smaller facilities, since sediment would have to be removed more often to retain storage volume.

Table C-6
Average Phosphorus Removal of Various Stormwater Control Measures

Stormwater Control Measure	UAL Reduction (%)
Diversion of first flush materials to a storage/percolation basin	99 +
Retention/percolation	100
Detention in natural swales/percolation	92
Percolation and collection by underdrains	93
Detention/sedimentation	76

SOURCE: Finnemore, E.J., Lynard, W.G. and J.A. Loop (in progress). "Urban Stormwater Management & Technology: Case Histories," U.S. EPA 68-03-2617, in: Lynard, W.G. and R. Field (1980)," Phosphorus in Stormwater: Sources and Treatability," in: Loehr, R.C., Martin, C.S. and W. Rast (eds.) (1980), *Phosphorus Management Strategies for Lakes*, Ann Arbor Science Publishers Inc., Ann Arbor, Michigan.

Table C-7
Costs of Different Types of Storage

Storage Type	Cost[a] ($/gal of storage)
Surface detention	.05
In-line	.36
Open, lined basin	.41
Covered basin	3.37
Basin plus sewer	1.46
Buried basin	.79
Buried-void space	.98
Buried, short detention	7.53
Open quarry	.33
Tunnels and appurtenances	.43

SOURCE: Lager, J.A. and W.G. Smith (1974). "Urban Stormwater Management and Technology: An Assessment," U.S. EPA-PB-240-687, Washington, D.C.

[a]Costs in 1980 dollars.

Table C-8
Costs of Various Runoff Control Measures

Method	Cost ($/ft)[a,b]
Diversion dike	4.24
Runoff interception trench	7.22
Strawbale sediment barrier	2.49
Sandbag sediment barrier	3.67
Filter berm	8.08
Filter fence	3.31
Filter inlet	2.30
Siltation berm	8.52

SOURCE: Lynard, W.G., Finnemore, E.J., Loop, J.A., and R.M. Finn (1980). "Urban Stormwater Management and Technology: Case Histories," EPA Report No. 600/8-80-035, Cincinnati, Ohio.

[a]Includes materials, labor and equipment.

[b]It is unknown what year the dollar figures represent.

Table C-9
Estimated Cost of Permanent Soil Stabilization Methods

Method	Unit	Materials	Labor	Equipment	Total Cost
Rock retaining wall (4 ft. high)	$/ft.	5	12	10	27
Redwood retaining wall (3 ft. high)	$/ft.	12	10	3	25
Gabion retaining wall (3 ft. high)	$/ft.	10	8	3	21
Slope bottom bench	$/ft.	none	5	2	7
Wattling	$/ft.	0.3	1.9	0.1	2.30
Slope steeping	$/acre	none	320	250	570
Slope serration	$/acre	none	300	120	420

SOURCE for Table and Notes: Lynard, W.G., Finnemore, E.J., Loop, J.A., and R.M. Finn (1980). "Urban Stormwater Management and Technology: Case Histories," EPA Report No. 600/8-80-035, Cincinnati, Ohio.

NOTES:

Rock Retaining Wall. A low gravity wall constructed of rock materials to provide an aesthetically attractive method for physically stabilizing a slope.

Redwood Retaining Wall. A retaining wall constructed of redwood planking and posts to stabilize unstable slopes.

Gabions. Large, single- or multi-celled rectangular wire mesh boxes filled with rock and wired together for permanent slope or drainage stabilization and erosion control.

Slope Bottom Bench. A gently sloping surface at the base of a steeper slope to retain eroded material.

Wattling. Bundles of live cuttings from willows to stabilize slopes and provide revegetation. Wattling reduces slope lengths for surface runoff, increases water retention, and provides additional organic matter.

Slope Steeping. Continuous series of horizontal steps cut on the face of cut slopes to interrupt slope length and provide slope stabilization.

Slope Serration. Construction of approximately 10 inch horizontal steps on the entire face of a cut slope to provide stabilization benches which can support vegetation.

Table C-10
Estimated Cost of
Temporary Soil Stabilization Methods
for Urbanizing Areas

Method	Materials ($/acre)	Labor & Equipment ($/acre)	Total Cost ($/acre)
Jute matting	2,700	6,400	9,100
Paper fabric	2,900	6,600	9,500
Plastic netting	700	4,100	4,800
Wood excelsior matting	1,700	9,000	10,700
Fiberglass roving	1,900	2,100	4,000
Hydromulching	500	700	1,200
Chemicals and tackifiers	400	200	600
Wood chip application	750	100	850
Crushed gravel mulches[1]	620	180	800
Straw mulch[2]	150	530	680

SOURCE for Table and Definitions: Lynard, W.G., Finnemore, E.J., Loop, J.A., and R.M. Finn (1980). "Urban Stormwater Management and Technology: Case Histories," EPA Report No. 600/8-80-035, Cincinnati, Ohio.

[1]2.5 tons/acre.

[2]2.0 tons/acre.

NOTES:

Jute Matting. Mulch nets made of jute used for erosion control and protection of other mulches.

Matting in Drainage Channels. Application of jute matting or fiberglass roving for dust and erosion control in very small drainage channels with flow velocities less than 2 ft/s.

Plastic Netting. Monolithic plastic cloth-like material used over mulch, straw, or hydromulch.

Wood Excelsior Matting. Mat of wood excelsior fibers bonded to a paper or plastic used for dust and erosion control. Flows under mat should be prevented.

Fiberglass Roving. Matting of continuous strands of glass fibers and tacking agent. Used for dust and erosion control and as a mulch for seeded and unseeded areas.

Hydro-mulching. Mechanized rapid method for applying wood fiber mulch, and tacking agent with or without seeds to large areas.

Chemicals and Tackifiers. Plastics, organic seeding additives, asphaltic tacking agents and other products used to tack fibers to slopes for erosion and dust control.

Wood Chip Application. Temporary mulch and surface protection using chips of wood. Used for dust and erosion control during construction and as a mulch around plantings.

Crushed Gravel Mulches. Application of gravel or crushed stone as a mulch to stabilize soils during construction, or for low-use dirt roads, driveways, and areas of light vehicular use.

Straw Mulch. Application of staple straw as a protective cover over bare or seeded soil to reduce erosion and provide a mulch. Requires matting or other methods to hold it in place.

NOTES:

In most instances porous pavement is economically competitive with conventional pavement. By preserving natural drainage it decreases runoff and downstream pollution. Depending upon design, porous pavements can remove anywhere from 0 to 100 percent of the suspended solids in the runoff.

Table C-11
Annual Cost
of Porous Pavement

Type of Use	Cost ($/sq. yd.)[1]
Residential Street	
Low design level	1.11
High design level	1.12
Business Street	
Suburban	1.12
City	1.34
Highway	
Two lane	1.29
Four lane	
Asphalt surface	1.48
Portland cement concrete surface	1.51
Parking lot	1.11
Playground	1.11

SOURCE: Poertner, H.G. (1974). "Practices in Detention of Urban Stormwater Runoff," American Public Works Association Special Report No. 43.

[1]Costs assumed to originally be in 1974 dollars. Dollars shown are 1980 dollars amortized over a 25-year period.

NOTES:

Regular flushing of sewers can reduce pollution from combined sewer overflow events. It is especially beneficial in areas with low slopes where the average dry weather flow is not strong enough to keep fine materials in suspension long enough to transport them to the treatment plant. In such cases the "shockloading" effect accompanying the first flush of a sewer line during a storm is particularly great. By preventing accumulation of materials, flushing of sewer lines also increases the overall capacity and efficiency of the system in handling and treating wet weather flows.

Table C-12
Annual Cost and
Percent Phosphorus Removal
of Sewer Flushing

Flush Stations per 9 Acres	Total Cost[a] ($/acre)	UAL Reduction (%)
2	362.75	61
4	728.78	72

SOURCE: Lager, J.A. and W.G. Smith (1974). "Urban Stormwater Management and Technology: An Assessment," EPA Report No. EPA-PB-240-687, Washington, D.C. Data obtained from a demonstration project in Detroit, Michigan.

[a]Costs are in 1980 dollars averaged over 25-year life of project.

Table C-13
Costs and Percent Removal of Biochemical Oxygen Demand from Combined Sewer Overflow Abatement Alternatives[1]

Source Controls[2]	% BOD Removal	Cost ($/lb. BOD)
Streetsweeping	2 - 11	3.63 - 9.08
Catch basin cleaning	0	> 60.50
Sewer flushing	18 - 32	1.14 - 4.84
Collection System Controls[3]		
Sewer separation	54 - 65	29.88
Swirl concentrators	32 - 56	2.86 - 4.98
In-line storage	site specific	1.56 - 4.98
Roof drain disconnection	site specific	> 60.50
Storage/Treatment Systems[4]		
2,000 acre—Level 1	10 - 16	5.85 - 7.47
Level 2	16 - 35	4.23 - 5.85
Level 3	35 - 61	3.86 - 4.23
Level 4	61 - 87	3.86 - 5.23
Level 5	87 - 95	5.23 - 17.43
200 acre—Level 3	56 - 90	9.96 - 16.19
20 acre—Level 3	65 - 90	37.35 - 51.05
Advanced Wastewater Treatment[5]		
Effluent BOD = 15-25 mg/L	—	2.37 - 3.24
Effluent BOD = 10 mg/L	—	3.49 - 4.98
Effluent BOD = 5 mg/L	—	6.10 - 8.72

SOURCE: Graham, P.H. (1978). "Report to Congress on Control of Combined Sewer Overflow in the United States," EPA Report No. 430/9-78-006.

[1]Assumptions common to all calculations:
Population density = 16.73/acre
BOD_5 yield = 136.23 lb/acre-year
Annual runoff = 16.5 inches
Sludge pumping costs are included.

[2]Original dollar figures were for 1978. Costs shown are in 1980 dollars. Conversion made by assuming 10% inflation rate per year.

[3]Original dollar figures were for 1978. Costs shown are in first quarter 1981 dollars.

[4]Storage/Treatment systems are based on runoff from a 2,000 acre drainage basin unless otherwise stated. Treatment levels are defined as follows:

Level 1 = Storage
Level 2 = Storage and microscreening
Level 3 = Storage, microscreening, and sedimentation-flocculation
Level 4 = Storage, microscreening, sedimentation-flocculation, and high-rate filtration
Level 5 = Storage, microscreening, dissolved air flotation, sedimentation-flocculation, and high-rate filtration

[5]Advanced wastewater treatment costs are incremented costs incurred above secondary treatment. Secondary treatment will remove approximately 85% of the BOD_5 from the dry-weather flow at a cost of $0.50 to $0.70 per pound of BOD_5 removed. The unit costs reported are those required to remove the remaining BOD_5 from the dry-weather flow.

Table C-14
Pollutant Removal Efficiencies of Street Cleaning Operations

Pollutant	Average Removal (lbs./curb-mile)	Average Unit Cost[a] ($/lb. removed)
Total Solids	205	0.11
Suspended Solids	103	0.22
Chemical Oxygen Demand	22	1.04
Biochemical Oxygen Demand	11	2.07
Orthophosphate	0.03	951.40
Kjeldahl Nitrogen	0.96	46.00
Lead	0.57	39.20
Zinc	0.11	191.40
Chromium	0.09	246.60
Copper	0.18	134.40
Cadmium	0.005	35376.00

SOURCE: Adapted from Lynard, W.G., Finnemore, E.J., Loop, J.A., and R.M. Finn (1980). "Urban Stormwater Management and Technology: Case Histories," EPA Report No. 600/8-80-035, Cincinnati, Ohio.

[a]It is unknown what year the dollar figures represent.

NOTES:

In most large cities streetsweeping equipment is already in use and little additional cost will be involved in shifting the focus of the operation to pollution abatement.

Generally, vacuum sweepers appear to be the most cost-effective. Vacuum sweepers are also less affected by variations in the street surface.

Table C-15
Annual Costs and Percent Removal of Total Solids by Streetsweeping

Land Use	Cost[a] ($/curb mile)	Cost ($/acre)	Removal of Total Solids[b] (%)
Residential	17.40	27.43	33-43
Commercial	17.40	32.54	34-40
Industrial	17.40	15.82	not reported

SOURCE: Pitt, R. (1979). "Demonstration of Nonpoint Pollution Abatement through Improved Street Cleaning Practices," EPA Report No. 600/2-79-161, Washington, D.C.

[a]Costs are based on 26 passes/year, 1 pass every 2 weeks. Machinery used varied. Costs are 75 percent labor and are in 1980 dollars.

[b]Based on moderate to heavy pollutant loads. Percentage removal of phosphorus is "very similar."

Table C-16
A Comparison of Streetsweeper Pollutant Recovery Efficiencies

Pollutant	% Recovery Efficiency by Streetsweeper Type	
	Broom	Vacuum or Broom/Vacuum Combination
Total Solids	55	80
Volatile Solids	50	80
BOD	45	80
COD	30	80
Nitrates	35	70
Phosphates	20	70
Heavy Metals	50	90

SOURCE: Graham P., (1979). "1978 Needs Survey Cost Methodology For Control of Combined Sewer Overflow and Stormwater Discharges," EPA Report No. 430/9-79-003, Washington, D.C.

Table C-17
Annual Street Cleaning Costs of Broom Sweeper

Item	Costs[a] ($/yr)	Percentage of Total
Maintenance Supplies[b]	97,000	12
Operation Supplies[c]	30,000	3
Debris Transfer and Disposal	67,000	8
Equipment Depreciation	32,000	3
Labor[d]	604,000	74

SOURCE: Lynard, W.G., Finnemore, E.J., Loop, J.A., and R.M. Finn (1980). "Urban Stormwater Management and Technology: Case Histories," EPA Report No. 600/8-80-035, Cincinnati, Ohio. Data from San Jose, California, study.

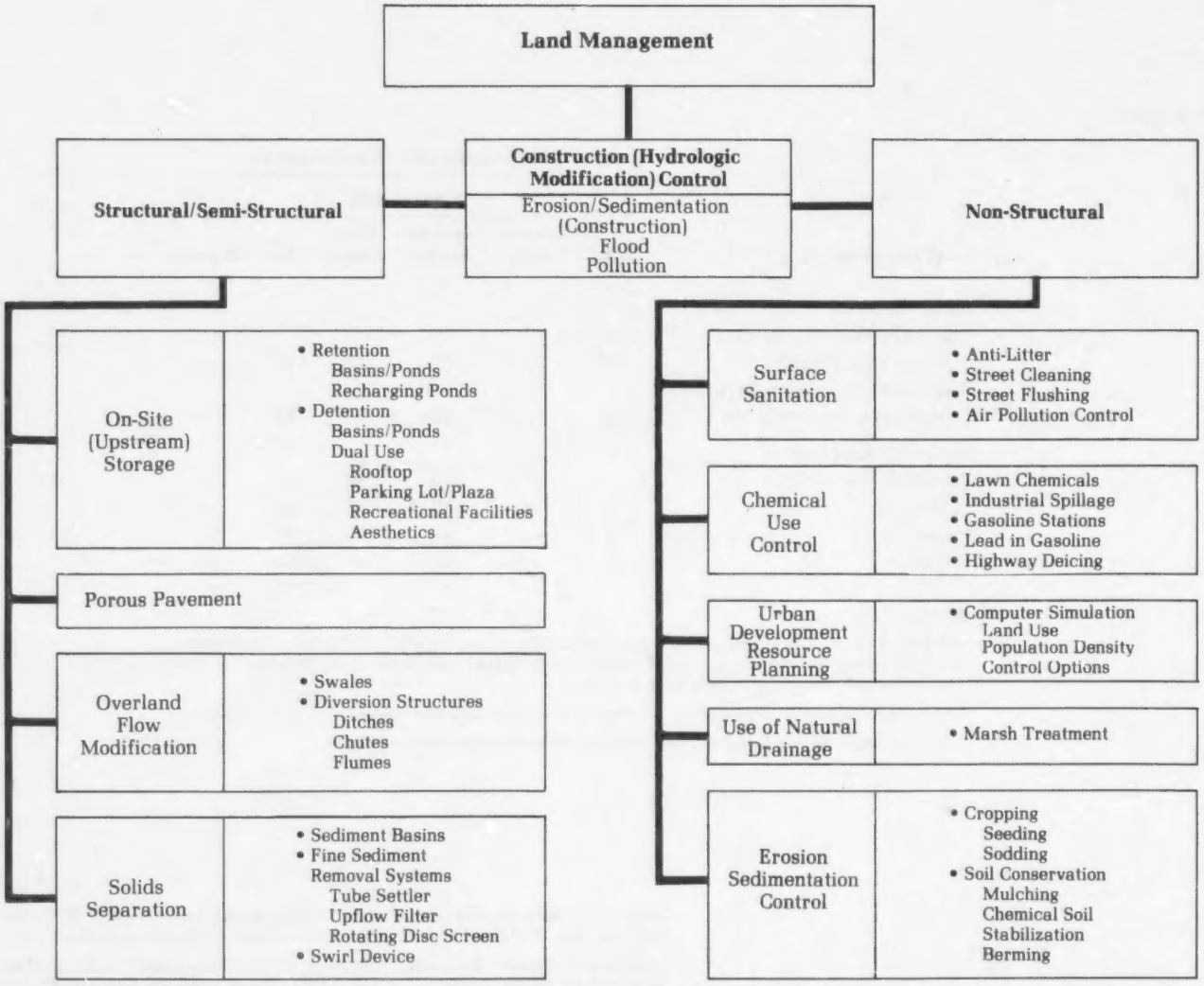
[a]It is unknown what year the dollar figures represent.

[b]Includes broom replacements.

[c]Tires, fuel and oil.

[d]Includes sweeper operators, maintenance personnel, supervisors, warehouse, secretary and overhead costs.

Figure C-1
Methods for Controlling Urban Runoff Pollution



SOURCE: Field, R., Tafuni, A., and H. Masters (1977), "Urban Runoff Pollution Control Technology Review," EPA Report No. 600/2-77-047, Cincinnati, Ohio.

Appendix D
Cropland and Other Rural Runoff: Pollutant Loadings and Controls

Table D-1
Total Phosphorus Unit Area Loads for Rural Land

Land Use Intensity	Total Phosphorus UAL (kg/km²/yr)					
	Type of Soil[a]					
	Sand	Coarse Loam	Medium Loam	Fine Loam	Clay	Organic
Rural Cropland						
Cultivated Fields—row crop (low animal density)	25	65	85	105	125[b]	—
Cultivated Fields—mixed farming (medium animal density)	10	20	30	55	85	—
Rural Non-Cropland						
Pasture/Range—dairy	5	5	10	40	60	—
Grassland	5	5	10	15	25	—
Forest	5	—	—	—	10[c]	—
Wetlands	—	—	—	—	—	0

Source:

[a]Adapted from Pollution from Land Use Activities Reference Group (PLUARG) (1978). "Environmental Management Strategy for the Great Lakes," International Joint Commission, Windsor, Ontario. Mainly for midwestern soils. May vary by regions.

[b]Unit area loads may be higher when soil has an unusually high clay content.

[c]Unit area loads may be higher in certain unique forested areas with clay soils.

SOURCES: ►

[a]Eacker, C. (1981). Information is derived from the Saline Valley Rural Clean Water Program Project in Southeast Michigan. Costs shown are in 1981 dollars.

[b]Skimin, W.E., Powers, E.C., and E.A. Jarecki (1978). "An Evaluation of Alternatives and Costs for Nonpoint Source Controls in the United States Great Lakes Basin," International Joint Commission, Windsor, Ontario. It is unknown what year the dollar figures represent.

Table D-2
Costs of Various Rural Runoff Control Measures

Practice	Unit Cost
Permanent Vegetative Cover	$125.00/acre[a]
Animal Waste Management System	$30,000.00/unit[a]
Stripcropping System	$6.00/acre[b] $20.00/acre[a]
Diversion System	$0.70/ft.-$5.00/ft.
Waterway System	$200.00/acre[a]
Conservation Tillage System	$0/acre[b] $9.00/acre[a]
Stream Protection System	$2.00/ft.[a]
Sediment Retention, Erosion or Water Control Structures	$2,500.00/unit[a]
Tile Drain	$.80/ft.[b]
Contour Farming	$4.00/acre[b]
Terrace System	$1.00/ft.[b]
Cover Cropping	$18.00/acre[b]
Fertilizer Management	$6.00/acre[a]

NOTES:

Permanent Vegetative Cover. Improves water quality by establishing permanent vegetative cover on farm or ranch land to prevent excessive runoff or soil loss. Permanent vegetative cover may also be applied to critical areas such as gullies or banks which are major sources of sediment.

Animal Waste Management System. Facilities for the storage and handling of livestock and poultry wastes.

Stripcropping. A tillage system in which the field is subdivided into alternate strips of erosion-resistant crops and erosion-susceptible crops or fallow.

Diversion System. The installation of channels which intercept excess stormwater runoff which would otherwise flow across arable land contributing to a water pollution problem.

Waterway System. The installation of water courses which serve as outlets for runoff channels or drains. The waterway conveys excess surface runoff at non-erosive velocities to a natural water course or impoundment. The waterway is protected from erosion with establishment of sod cover of perennial grasses or legumes.

Stream Protection System. Includes the installation of vegetable filter strips, protective fencing, livestock crossings and livestock water facilities to protect streams from sediment.

Contour Farming. A tillage system in which strips of an erosion-resistant crop and erosion-susceptible crop are alternated along the contour.

Terrace System. Constructed to convey excess water safely in areas of abundant rainfall. Bench terraces are adapted to slopes of 25 to 30 percent and are not common in the U.S. because farm machinery cannot be used over them. Broad base terraces are more common. This is a broad surface channel or embankment constructed across the slope of rolling land.

Tile Drain. Form of subsurface drain in which tile in the form of fired clay, concrete or corregated plastic is laid in the bottom of a trench. The tile line is given a slight slope to cause the water to flow to the outlet.

Cover Cropping. A tillage system in which a crop is planted specifically to control erosion. Rye, clover and vetch are examples of cover crops. It is usually planted for protection during the time money crops are not grown on a tract of land, but may also be planted between rows of crops. Cover crops provide the additional benefit of returning organic matter to the soil.

Fertilizer Management. Includes changes in the fertilizer rate, time and/or method of application to achieve control over nutrient movement in critical areas contributing to water pollution.

Table D-3
A Comparison of Soil Loss Reductions Under Different Conservation Tillage Practices

Farm Practice	% Reduction in Soil Loss Compared to Conventional Tillage
No-Till	76[a]-85[b]
No-Till—Corn	91[c]
No-Till—Soybeans	85[c]
Reduced Till	40[a]
Till-Plant	60[b]
Chisel-Plow	94[b]
Disk Chisel—Corn	89[c]
Disk Chisel—Soybeans	71[c]

SOURCES:

[a]Crumrine, J.P. and D.U. Wurm (1980). "Conservation Tillage Practices to Control Agricultural Pollution." Lake Erie Wastewater Management Study. U.S. Army Corps of Engineers. Buffalo District, Buffalo, New York.

[b]Mannering, J.V. et al. (1975). "Tillage for Moisture Conservation," in: Griffith, D.R., Mannering, J.V., and W.C. Moldenhauer (1977). "Conservation Tillage in the Eastern Corn Belt."

[c]Oschwald, W. and J. Seimens (1976). "Conservation Tillage: A Perspective," in: Griffith et al. (1977), op. cit.

NOTES:

Conservation Tillage

Conservation tillage methods have been defined by the U.S. Department of Agriculture as "any tillage sequence that reduces loss of soil or water."[1] These systems leave a rough soil surface or a mulch of plant residue which protects against wind and water erosion. Residue acts as an umbrella, reducing the impact of rainfall, and as a barrier to slow runoff. In addition, residue increases infiltration by preventing crusting of the soil surface.

Conservation tillage includes a wide range of practices. Three such systems are described below.

Till-Plant. In till-plant the number of tillage operations is reduced, but a moldboard plow or similar tool is still used on an annual basis, in this case in the fall. Till plant minimizes tillage by eliminating spring plowing. Planting occurs in the ridges made the previous fall with a cultivator or disk-harrow.[2] The reduction in soil erosion can be substantial, but the occurrence of intense rainstorms after the crop residue has been buried will result in near-maximum soil loss.

Chisel-Plow. Another conservation tillage system utilizes non-inversion equipment such as the chisel-plow. Chiseling loosens the soil and leaves up to three-fourths of the residue at or near the surface.

Often a combination of conservation tillage methods are employed, such as chisel plowing in conjunction with ridge planting. The latter technique involves planting row crops on soil ridges. This accelerates soil drying and warming, which is often a problem on fields in which tillage is reduced.

The chisel-plow conservation tillage system effectively controls erosion on level to gently sloping land. On steeper land, it can enhance the effectiveness of other conservation practices such as terraces and contour plowing.

No-Till. No-till farming is a special case of conservation tillage. It is the planting of crops in narrow slots opened in the seedbed without any other physical disturbance of the soil. The seed is planted in crop residue from the previous year or in herbicide burned winter cover or meadow vegetation.

Maintaining crop residue on the soil surface throughout the year has been shown to reduce the potential soil loss by 65 to 85 percent of that from conventionally tilled land.[3] In addition to the decrease in soil erosion and associated water quality benefits, no-till farming has the potential to lower fuel use, save farmers' time, and produce greater or nearly equal crop yields on properly selected soils.

SOURCE: Excerpted from: Monteith, T.J., Basie, M.P. and R.A.C. Sullivan (1981). "Environmental & Economic Implications of Conservation Tillage Practices in the Great Lakes Basin.

[1]Bauder et al. (1979). "Tillage: Its Role in Controlling Soil Erosion by Water," Agricultural Extension Service Folder No. 497, University of Minnesota.

[2]Ibid.

[3]Ibid.

Table D-4
Reductions in Annual Soil Losses[a] and Phosphorus Loadings[b] Associated with Different Farm Practices, as Compared to Continuous Corn with Conventional Tillage

Farm Practice	Conventional Till	No-Till	Chisel Plow	Terracing	Percent Reduction					
					Uplands		Ridge		Lowlands	
					Soil Loss	P UAL	Soil Loss	P UAL	Soil Loss	P UAL
Continuous Corn	●			●	28.7	17-26	28.6	17-26	29.4	18-26
Continuous Corn			●		54.7	33-49	54.9	33-49	52.9	32-48
Continuous Corn			●	●	67.9	41-61	67.0	40-60	67.6	41-61
Continuous Corn		●			73.6	44-66	73.6	44-66	73.5	44-66
Corn-Soybean[c]	●				2.6[c]	2[c]	3.3[c]	2-3[c]	2.9[c]	2.3[c]
Corn-Soybean			●		42.6	26-38	42.9	26-39	41.2	25.37
Corn-Soybean		●			57.0	34-51	57.1	34-51	55.9	34-50
Corn-Soybean		●		●	69.4	42-62	69.2	42-62	70.6	42-64
Corn-Soybean-Wheat-Hay	●[d]				83.8	50-75	83.5	50-75	85.3	51-77
Corn-Soybean-Wheat-Hay		●			89.8	54-81	90.1	54-81	88.2	53-79

SOURCE: Meta Systems, Inc., (1979). "Costs and Water Quality Impacts of Reducing Agricultural Nonpoint Source Pollution. An Analysis Methodology," EPA Report No. EPA-600/5-79-009, Environmental Research Laboratory, U.S. EPA, Athens, Georgia.

[a]Annual soil loss (tons/acre) with continuous corn, conventional tillage: Uplands—26.5; Ride—9.1; Lowlands—3.4

[b]Percent reduction in phosphorus loss is assumed to be 60% to 90% of the percent reduction in soil loss, based on work for the Lake Erie Wastewater Management Study by the U.S. Army Corps of Engineers, Buffalo District, Buffalo, New York, published in 1979.

[c]These figures represent a percentage increase in annual soil loss and phosphorus unit area load.

[d]Conventional tillage is for corn only.

Table D-5
A Comparison of Revenues and Costs of Different Farm Practices with Corn and Soybeans (per acre)

		No-Till		Reduced Till		Conventional Till	
		Range	Average	Range	Average	Range	Average
Material Costs[1]	Corn	$163.33-244.06	$200.40	$162.30-232.02	$195.28	$145.13-214.71	$181.23
	Soybeans	$ 70.48-136.60	$105.84	$ 63.18	$ 63.18	$ 60.63-108.15	$ 78.49
Machine Costs[2]	Corn	$ 46.53- 59.12	$ 50.99	$ 51.37- 64.34	$ 59.62	$ 64.49- 80.36	$ 72.25
	Soybeans	$ 39.31- 45.04	$ 42.86	$ 55.17	$ 55.17	$ 54.99- 67.87	$ 60.94
Total Costs	Corn	$216.45-299.26	$251.39	$226.64-294.86	$254.90	$225.49-290.31	$253.48
	Soybeans	$111.49-181.56	$148.70	$118.35	$118.35	$115.62-176.02	$139.43
Return (Net)[3]	Corn	$- 9.94-200.47	$ 83.79	$ 18.60-191.01	$ 79.94	$ 55.02-223.88	$133.86
	Soybeans	$178.16-290.86	$227.35	$187.65	$187.65	$161.14-268.80	$221.21
Yield (Bu/Ac.)	Corn	81.5-155.1	118.05	98.6-146.7	117.98	112.2-174.0	135.60
	Soybeans	44.6-54.8	50.24	40.78	40.78	43.1-52.1	48.22

SOURCE: Honey Creek Joint Board of Supervisors (1981). "Honey Creek Watershed Project: Tillage Demonstration Results, 1980." U.S. Army Corps of Engineers, Buffalo District, Buffalo, New York.

[1]1980 material costs include: seed, lime, miscellaneous, fertilizer, herbicides, and interest on operating capital.

[2]1980 machine costs include: custom rates for tillage, planting, harvesting, trucking, application of fertilizers, herbicides and insecticides.

[3]1980 return (net) = Crop value minus total costs. Crop value obtained by taking yields at 15.5% moisture, multiplying by the base price of $3.00 (current market price), minus the wet bushels produced per acre times the drying charges (local elevator schedule).

Table D-6
Change in Net Return and Actual Yield for Corn Under Alternative Tillage Practices, by Soil Management Group

Tillage System	Soil Management Group[a]					
	I		II		III	
	% Change in Net Return	% Change in Yield	% Change in Net Return	% Change in Yield	% Change in Net Return	% Change in Yield
Conventional Till	—	—	—	—	—	—
Chisel Plow Till	+ 9.2	- 0.2	+ 5.4	+ 0.6	+ 10.0	+ 4.5
Minimum Tillage	+ 21.7	+ 7.0	+ 13.8	+ 6.4	+ 15.2	+ 6.6
No Tillage	+ 12.7	+ 0.6	+ 4.1	+ 0.9	- 2.2	+ 1.3

SOURCE: Hemmer, R.F. and D.L. Forster (1981). "Farmer Experiences with Alternative Tillage Practices in the Western Lake Erie Basin," U.S. Army Corps of Engineers, Buffalo District, New York. Data from corn grown in 10 selected counties in the western Lake Erie basin.

[a]Soil Management Groups are as follows:

Management Group I: Soils included in this group should have yield response to no tillage equal to or greater than conventional tillage. Soils are moderately well, well, and excessively well-drained. They have silt loam, sandy loam, or loamy fine sand surface texture. They are low in organic matter.

Management Group II: These soils should have yield responses to no tillage nearly equal to conventional tillage if soil drainage has been improved. These soils are somewhat poorly drained in their natural state. They have a silt loam, loam, sandy loam, or loamy fine sand surface texture. They are low in organic matter.

Management Group III: These soils yield less with no tillage than conventional tillage. They are somewhat poorly to very poorly-drained. Tile does not provide adequate drainage. Surface texture is loam, silt loam, or silty clay loam. Most of these soils are low in organic matter.

Table D-7
Nonpoint Pollution from Silviculture Operations:
Factors Influencing Sediment Load and Control Measures

Sediment delivery factors	Preventive	Mitigative
Water availability	Control over the rainfall rate is not likely to occur because it is a function of overall weather patterns.	
	Use management practices that maintain high infiltration rates. Avoid such things as soil compaction which changes soil structure and permeability. Control of soil moisture content by high consumptive use promotes infiltration.	Increase infiltration rates by breaking surface crusts, and incorporating organic matter or other soil amendments to improve aggregation of soil particles. Promote vegetative growth for high consumptive water use and desirable soil structure development.
	Where snowmelt is influential, use management practices which will not create significant increases in the amount of solar energy reaching the snow pack.	Reduce snowmelt runoff rates by increasing the interception of solar energy above the snow surface.
Texture of eroded material	Soil texture is controlled by soil-forming factors that are generally related to mineralogy and weathering.	
	Maintain natural, stable soil aggregates which will act as a coarse-textured material in response to sediment delivery forces.	Use soil amendments which promote flocculation and development of aggregates.
Ground cover	Control and design forest management activities to minimize forest floor disturbance.	Add mulch, establish vegetation, distribute residues, or use other practices to create long tortuous pathways for water flow and sediment delivery.
Slope shape	Control location and design of various types of construction and other activities that would create adverse slope shapes.	Design concave slope segments for sediment delivery control on construction sites or with other activities.
Slope gradient	Control location and design of various types of construction activities to minimize the creation of steep slopes.	Reduce slope gradients created by construction and other activities wherever possible.
Delivery distance	Locate activities well away from stream channels to maintain long delivery paths.	Relocate activity sites to increase overall delivery distance to a stream channel.
Surface roughness	Design activities to maintain natural surface roughness. Avoid creating channels that shortcut natural tortuous pathways.	Create ridges and depressions on the surface to trap sediment and increase water infiltration.
Site specific factors	This will depend upon the characteristics of the chosen site factor.	

SOURCE: Mulkey, L. (1980). "An Approach to Water Resources Evaluation of Non-Point Silviculture Sources," EPA-600/8-80-012, Washington, D.C.

Appendix E
Sandusky River Basin Example

This example is developed fully in Monteith *et al.*, 1980. Only the basic assumptions and the worksheets are presented here.

Municipal

Stage I Control: chemical precipitation to reduce the total phosphorus effluent concentration to 1.0 mg/L.

Stage II Control: additional treatment to further reduce the total phosphorus effluent concentration from 1.0 mg/L to 0.5 mg/L.

Stormwater Runoff

Stage I Control: streetsweeping at 7-day intervals with vacuum sweepers.

Stage II Control: Stage I control plus detention and sedimentation of stormwater runoff.

Implementing the Stage I program is assumed to result in a 25 percent reduction in the uncontrolled diffuse loading from all separate sewered areas. Implementation of Stage II programs will realize another 20 percent total phosphorus load reduction from the initial stormwater load.

Stage I Control: streetsweeping at 7-day intervals with vacuum sweepers.

Stage II Control: Stage I control plus detention and treatment of the combined sewer overflow.

The Stage I program results in about a 5 percent reduction in the total phosphorus load, and Stage II will result in additional 25 percent reduction in the total phosphorus loading.

Rural Cropland

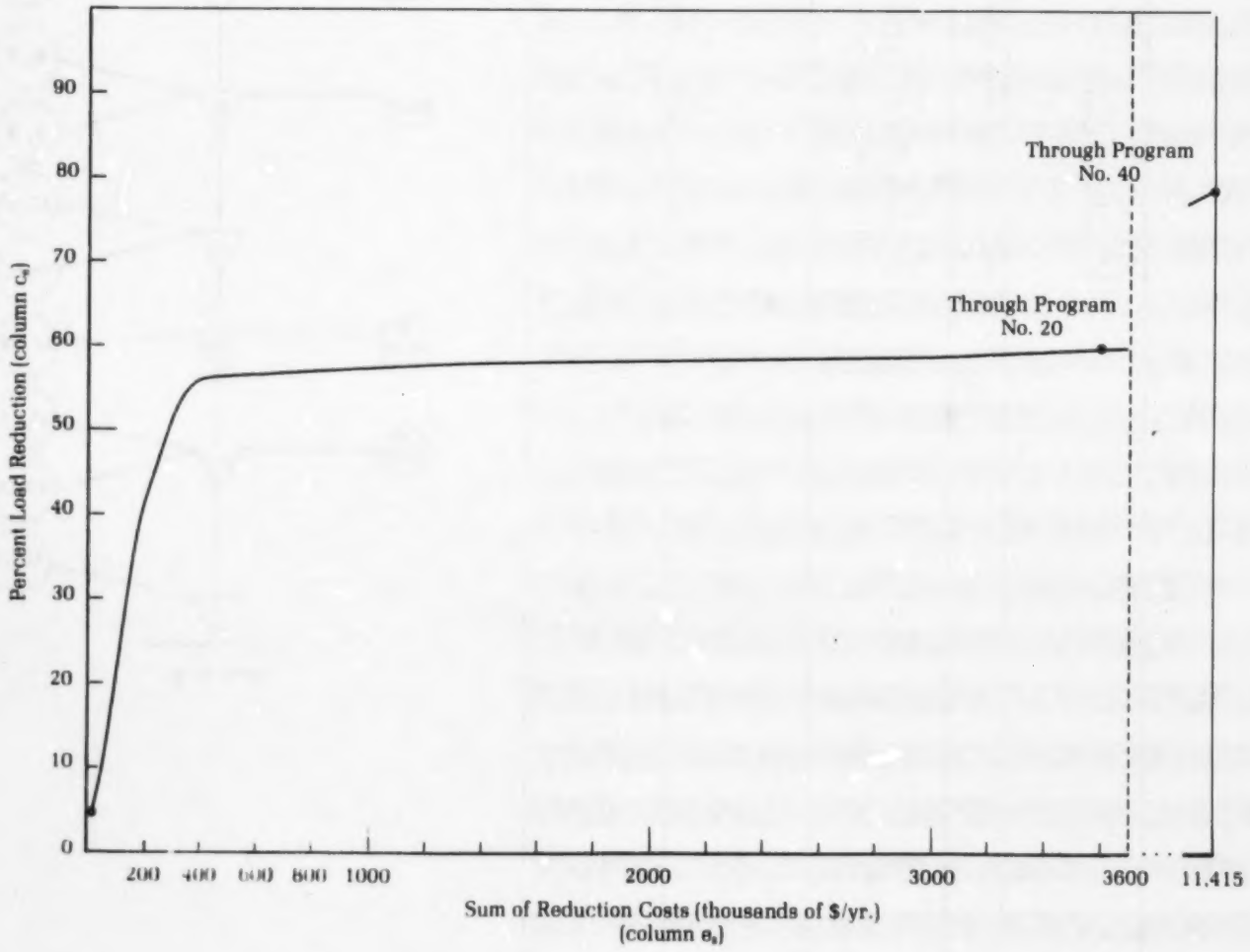
Stage I Control: technical assistance to educate farmers on the techniques and economic advantages of adopting conservation tillage practices.

Stage II Control: Stage I control plus application of more intensive conservation tillage practices (i.e., no-till where soils will support it).

NOTES:

By plotting the WATERSHED results from Worksheet 8, the point at which the implementation of control programs yields a diminished return on the investment made can be seen. Figure 1 shows a plot of the sum of the program costs (from column e_s) versus the sum of the percent load reduction (from column c_s). Good load reduction occurs as programs are implemented up to the funding level of $400,000 per year. In fact, the WATERSHED results show an estimated 56 percent reduction in the total phosphorus load for a cost of around $430,000 per year (programs ranked 1 through 14). After this point the graph flattens out considerably. The next 20 percent reduction (programs ranked 15 through 29), up to a total of 76 percent, is estimated to cost over $8 million *more* per year than the initial 56 percent reduction. Finally, the last 5 percent of the total phosphorus load that can be removed (programs ranked 30 through 40), for a total of 81 percent, is estimated to cost another $2.9 million per year for a total of $11.4 million per year if all programs were implemented.

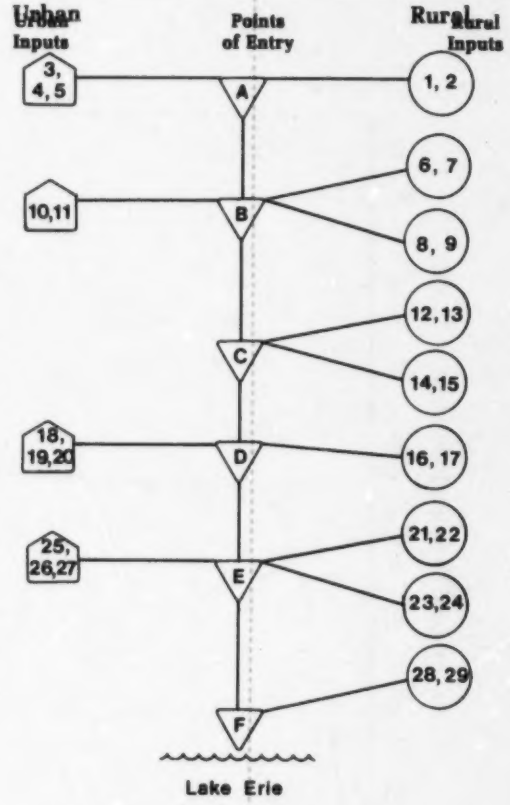
Figure E-1
Reduction Costs for
Total Phosphorus vs. Percent Load Reduction
Sandusky River Basin Example
(from Worksheet 8)



Physical Layout

Worksheet 1

Source	Position	Point of entry	Area (km²)	Surface Features		Diagram
				Soils	Other	
Loss Creek	1,2	A	230			
Bucyrus City	3,4,5	A	8.5			
Broken Sword	6,7	B	217			
Upper Sandusky River	8,9	B	325			
Upper Sandusky City	10,11	B	6.7			
Tymochtee Creek	12,13	C	593			
Middle Sandusky	14,15	C	640			
Honey Creek	16,17	D	386			
Tiffin City	18,19,20	D	17.4			
Wolf Creek	21,22	E	385			
Rock Creek	23,24	E	464			
Fremont City	25,26,27	E	13.7			
Lower Sandusky	28,29	F	730			



Point and Urban Runoff Loads

Worksheet 2

Source	Column ➤ a_2	b_2	c_2	d_2	e_2	f_2	g_2	h_2	i_2	j_2	k_2	l_2
	Point			Separate Storm			Combined			Unsewered*		
	Position	Flow (mgd)	Conc. (mg/L)	Load (kg/yr)	Area (km^2)	UAL** ($kg/km^2/yr$)	Load (kg/yr)	Area (km^2)	UAL** ($kg/km^2/yr$)	Load (kg/yr)	Area (km^2)	UAL** ($kg/km^2/yr$)	Load (kg/yr)
INITIAL CONDITION												
Bucyrus City	3,4,5	2.5	4.0	13,800	1.3	250	320	7.2	900	6,500	0	--	
Upper Sandusky City	10,11	1.5	4.0	8,300	0	---	---	6.7	250	1,700	0	--	
Tiffin City	18,19,20	3.2	4.0	17,700	7.0	250	1,800	10.4	1,000	10,400	0	--	
Fremont	25,26,27	5.1	4.0	28,200	1.4	250	350	12.3	1,000	12,300	0	--	
TOTAL				68,000	9.7		2,500	36.6		30,900			
STAGE I												
Bucyrus City	3,4,5	2.5	1.0	3,400	1.3	188	240	7.2	846	6,091			
Upper Sandusky City	10,11	1.5	1.0	2,100	---	---	---	6.7	235	1,574			
Tiffin City	18,19,20	3.2	1.0	4,400	7.0	188	1,300	10.4	940	9,776			
Fremont	25,26,27	5.1	1.0	7,000	1.4	188	260	12.3	940	11,562			
TOTAL				16,900			1,800			29,003			
STAGE II												
Bucyrus City	3,4,5	2.5	0.5	1,728	1.3	140	182	7.2	630	4,536			
Upper Sandusky City	10,11	1.5	0.5	1,036	---	---	---	6.7	175	1,172			
Tiffin City	18,19,20	3.2	0.5	2,211	7.0	140	980	10.4	700	7,280			
Fremont City	25,26,27	5.1	0.5	3,524	1.4	140	196	12.3	700	8,610			
TOTAL				8,499			1,358			21,598			

$c_2 = a_2 \times b_2 \times 1{,}382$: where 1,382 is the conversion factor (mg/L × mgd × 1,382) = kg/yr.
$f_2 = d_2 \times e_2$
$i_2 = g_2 \times h_2$
$j_2 = i_2 = k_2$

*Can include construction sites or septic tank areas.
**UAL: Unit Area Load

Rural Non-Cropland Loads

Worksheet 3

Source	Column ►	a_2	b_2	c_2	d_2	e_2	f_2	g_2	h_2	i_2	j_2
		Grass			Woodland			Other**			
	Position	Area* (km^2)	UAL ($kg/km^2/yr$)	Load (kg/yr)	Area* (km^2)	UAL ($kg/km^2/yr$)	Load (kg/yr)	Area* (km^2)	UAL ($kg/km^2/yr$)	Load (kg/yr)	Total Non-Cropland Load (kg/yr)
Loss Creek	2	11.83	10	118	25.04	10	250				368
Broken Sword	7	3.59	10	36	18.17	10	180				216
Upper Sandusky River	9	12.81	10	128	34.38	10	344				472
Tymochtee	13	9.04	25	226	47.13	10	471				697
Middle Sandusky	15	17.27	10	173	67.96	10	680				853
Honey Creek	17	3.17	10	31	44.07	10	441				472
Wolf Creek	22	7.57	10	76	22.89	10	229				305
Rock Creek	24	12.14	10	121	56.47	10	565				686
Lower Sandusky (Soil 1)	29	10.00	25	250	74.54	10	745				1,077
Lower Sandusky (Soil 2)	29	8.25	10	82	---	10	---				---
		95.67			390.65			274.88	Water, Wetlands		
TOTAL				1,241			3,905				5,146

$c_2 = a_2 \times b_2$
$f_2 = d_2 \times e_2$
$i_2 = g_2 \times h_2$
$j_2 = c_2 \times f_2 + i_2$

*Weighted Extrapolation
**Can include septic tank failures
UAL—Unit Area Load

Rural Cropland Loads

Worksheet 4

Source	Column ➤	a_s	Universal Soil Loss Equation Coefficients					b_s	c_s	d_s	e_s	f_s	g_s	h_s
	Position	Cropland Area (km^2)	Rainfall & Runoff R	Soil Erodibility K	Topographic LS	Cover & Management C	Support Practice P	Soil Loss (t/ac/yr) A	Soil Loss ($mt/km^2/yr$) A	Total Gross Erosion (mt/yr)	Pollutant Delivery Ratio	PRE	UAL ($kg/km^2/yr$)	Total P (kg/yr)
INITIAL														
Loss Creek	1	18,984	125	.35	.402	.233	1	4.1	9.3	176,551				18.4
Broken Sword	6	18,719	125	.38	.424	.233	1	4.7	10.5	196,544				20.5
Upper Sandusky	8	27,460	130	.42	.426	.245	1	5.7	12.7	348,742				36.6
Tymochtee	12	52,840	138	.32	.357	.260	1	4.1	9.2	486,128				51.0
Middle Sandusky	14	54,236	138	.38	.381	.260	1	5.2	11.6	629,138				66.0
Honey Creek	16	34,355	125	.35	.338	.237	1	3.5	7.8	267,964				28.0
Wolf Creek	21	34,311	125	.29	.256	.237	1	2.2	5.0	171,555				18.0
Rock Creek	23	40,990	125	.34	.427	.237	1	4.3	9.6	393,504				41.2
L.Sandusky (Soil 1)	28	24,355	125	.32	.410	.268	1	4.4	9.9	241,114				25.2
L.Sandusky (Soil 2)	28	10,000	125	.28	.434	.237	1	3.6	8.1	81,000				8.5
TOTAL		316,250						4.2	9.5	2,992,250	.000105	NA	NA	313.4
STAGE I														
Loss Creek	1					.108		1.9	4.3	81,269			1.0	8.5
Broken Sword	6					.099		2.0	4.5	84,756			1.0	8.9
Upper Sandusky	8					.103		2.4	5.3	146,494			1.0	15.4
Tymochtee	12					.108		1.7	3.8	203,721			1.0	21.4
Middle Sandusky	14					.110		2.2	4.9	265,887			1.0	27.9
Honey Creek	16					.101		1.5	3.4	117,017			1.0	12.3
Wolf Creek	21					.108		1.0	2.2	75,938			1.0	8.0
Rock Creek	23					.105		1.9	4.2	171,635			1.0	18.0
L.Sandusky (Soil 1)	28					.116		1.9	4.2	102,601			1.0	10.8
L.Sandusky (Soil 2)	28					.099		1.5	3.4	34,468			1.0	3.6
TOTAL								1.8	4.0	1,283,786	.000105		1.0	134.8

$b_s = (R)(K)(LS)(C)(P)$

$c_s = b_s \times 2.243$

$d_s = c_s \times a_s$

e_s: Pollutant Delivery Ratio (PDR)—The ratio of pollutant to total gross erosion for Initial Case

f_s: Pollutant Reduction Efficiency (PRE)—The extent that a pollutant yield is decreased from a given decrease in potential gross erosion.

Rural Cropland Loads

Worksheet 4

Source	Column ➤	a_i	Universal Soil Loss Equation Coefficients					b_i	c_i	d_i	e_i	f_i	g_i	h_i
	Position	Cropland Area (km^2)	Rainfall & Runoff R	Soil Erodibility K	Topographic LS	Cover & Management C	Support Practice P	Soil Loss (t/ac/yr) A	Soil Loss ($mt/km^2/yr$) A	Total Gross Erosion (mt/yr)	Pollutant Delivery Ratio	PRE	UAL ($kg/km^2/yr$)	Total P (kg/yr)
STAGE II														
Loss Creek	1					.034		0.6	1.4	27,196		1.0		2.8
Broken Sword	6					.035		0.7	1.5	27,692		1.0		2.9
Upper Sandusky	8					.034		0.8	1.7	47,388		1.0		5.0
Tymochtee	12					.032		0.5	1.2	65,143		1.0		6.8
Middle Sandusky	14					.035		0.7	1.6	86,613		1.0		9.1
Honey Creek	16					.034		0.5	1.1	38,678		1.0		4.1
Wolf Creek	21					.032		0.3	0.7	25,309		1.0		2.6
Rock Creek	23					.033		0.6	1.4	56,460		1.0		5.9
L.Sandusky (Soil 1)	28					.036		0.6	1.4	33,572		1.0		3.5
L.Sandusky (Soil 2)	28					.033		0.5	1.1	11,278		1.0		1.2
TOTAL								0.6	1.3	419,329	.000105	1.0		44.0

b_i = (R)(K)(LS)(C)(P)

c_i = b_i × 2.243

d_i = c_i × a_i

e_i: Pollutant Delivery Ratio (PDR)—The ratio of pollutant to total gross erosion for Initial Case

f_i: Pollutant Reduction Efficiency (PRE)—The extent that a pollutant yield is decreased from a given decrease in potential gross erosion.

Loading Summary

Worksheet 5

Source	Column ➤	a_s	b_s	c_s	d_s	e_s
	Position	Initial Load to River Channel (kg/yr)	Load to River Channel with Controls in Place (kg/yr)		Load Reductions (kg/yr)	
			Stage I	Stage II	Stage I	Stage II
Loss Creek	1,2	18,868	8,868	3,163	10,000	5,700
Bucyrus - municipal	3	13,800	3,400	1,728	10,400	1,672
- storm	4	320	240	182	80	58
- combined	5	6,500	6,091	4,536	409	1,555
Broken Sword	6,7	20,816	9,116	3,116	11,700	6,000
Upper Sandusky River	8,9	37,072	15,872	5,472	21,200	10,400
Upper Sandusky - municipal	10	8,300	2,100	1,036	6,200	1,064
- combined	11	1,700	1,574	1,172	126	402
Tymochtee Creek	12,13	51,697	22,097	7,497	29,600	14,600
Middle Sandusky	14,15	66,853	28,753	9,953	38,100	18,800
Honey Creek	16,17	28,572	12,772	4,572	15,800	8,200
Tiffin - municipal	18	17,700	4,400	2,211	13,300	2,189
- storm	19	1,800	1,300	980	500	320
- combined	20	10,400	9,776	7,280	624	2,496
Wolf Creek	21,22	18,305	8,305	2,905	10,000	5,400
Rock Creek	23,24	41,986	18,686	6,586	23,300	12,100
Fremont - municipal	25	28,200	7,000	3,524	21,200	3,476
- storm	26	350	260	196	90	64
- combined	27	12,300	11,562	8,610	738	2,952
Lower Sandusky	28,29	34,877	15,477	5,777	19,400	9,700
TOTAL		420,416	187,649	82,301	232,767	107,148

a_s: Initial: municipal (c_i), storm (f_i), combined sewer (i_i), noncropland (j_i), cropland (h_i).
b_s: Stage I: municipal (c_1), storm (f_1), combined sewer (i_1), noncropland (j_1), cropland (h_1).
c_s: Stage II: municipal (c_2), storm (f_2), combined sewer (i_2), noncropland (j_2), cropland (h_2).
$d_s = a_s - b_s$: The loading reduction from the initial condition when Stage I is implemented.
$e_s = b_s - c_s$: The loading reduction from the Stage I condition when Stage II is implemented.

Program Costs

Worksheet 6

Source	Column ➤	a_s	b_s	c_s	d_s	e_s	f_s	g_s	h_s
		Nonpoint			Point			Total Cost of Program ($/yr)	
			($/km²/yr)			($/cap/yr)			
	Position	Area Treated (km²)	Initial to Stage I	Stage I to Stage II	Units Served	Initial to Stage I	Stage I to Stage II	Initial to Stage I	Stage I to Stage II
Loss Creek	1,2	139.8	65	3,000	--	---	---	12,337	569,400
Bucyrus - municipal	3	---	---	---	13,500	2.4	3.6	32,400	48,600
- storm	4	1.3	7,400	8,600	--	---	---	9,620	11,180
- combined	5	7.2	7,400	24,700	--	---	---	53,280	177,840
Broken Sword Creek	6,7	187.2	65	3,000	--	---	---	12,168	561,600
Upper Sandusky River	8,9	274.6	65	3,000	--	---	---	17,849	823,800
Upper Sandusky - municipal	10	---	---	---	6,250	2.4	3.6	15,000	22,500
- combined	11	6.7	7,400	24,700	--	---	---	49,530	165,490
Tymochtee Creek	12,13	528.4	65	3,000	--	---	---	34,346	1,585,200
Middle Sandusky	14,15	542.4	65	3,000	--	---	---	35,256	1,627,200
Honey Creek	16,17	343.6	65	3,000	--	---	---	22,334	1,030,800
Tiffin - municipal	18	---	---	---	26,000	2.4	3.6	62,400	93,600
- storm	19	7.0	7,400	8,600	--	---	---	51,800	60,200
- combined	20	10.4	7,400	24,700	--	---	---	76,960	256,880
Wolf Creek	21,22	343.1	65	3,000	--	---	---	22,302	1,029,300
Rock Creek	23,24	409.9	65	3,000	--	---	---	26,644	1,229,700
Fremont - municipal	25	---	---	---	19,730	2.4	3.6	47,352	71,028
- storm	26	1.4	7,400	8,600	--	---	---	10,360	12,040
- combined	27	12.3	7,400	24,700	--	---	---	91,020	303,810
Lower Sandusky	28,29	343.6	65	3,000	--	---	---	22,334	1,030,800
TOTAL								705,342	10,710,902

a_s: a_s cropland, or d_s or g_s or j_s urban land.
b_s: Unit area cost of going from the initial cropland condition to a Stage I cropland program.
c_s: Unit area cost of going from the Stage I cropland program to Stage II.
d_s: Units served (i.e., population served for municipal plants).
e_s: Unit cost of going from the initial point source load to a Stage I load.
f_s: Unit cost of going from the Stage I point source program to Stage II.
$g_s = a_s \times b_s$, or $d_s \times e_s$.
$h_s = a_s \times c_s$, or $d_s \times f_s$.

Cost-Effectiveness Analysis

Total P

Worksheet 7

Source	Column ➤ Position	a_i Effective Transmission	b_i Bio-Available Fraction	c_i Total Load to Surface Water (kg/yr)	d_i Load at Mouth (kg/yr)	e_i Load Reduction at Mouth (kg/yr)	f_i Cost of Program ($/yr)	g_i Cost Per Unit Removed at Mouth ($/kg)	h_i Cost-Effective Rank
STAGE I						STAGE I	STAGE I	STAGE I	
Loss Creek	1,2	1	NA	18,868	18,868	10,000	12,337	1.2	7
Bucyrus - municipal	3	1		13,800	13,800	10,400	32,400	3.1	12
- storm	4	1		320	320	80	9,620	120.2	27
- combined	5	1		6,500	6,500	409	53,280	130.3	33
Broken Sword	6,7	1		20,816	20,816	11,700	12,168	1.0	3
Upper Sandusky River	8,9	1		37,072	37,072	21,200	17,849	0.8	1
Upper Sandusky - municipal	10	1		8,300	8,300	6,200	15,000	2.4	11
- combined	11	1		1,700	1,700	126	49,580	393.5	34
Tymochtee Creek	12,13	1		51,697	51,697	29,600	34,346	1.2	5
Middle Sandusky	14,15	1		66,853	66,853	38,100	35,256	0.9	2
Honey Creek	16,17	1		28,572	28,572	15,800	22,334	1.4	8
Tiffin - municipal	18	1		17,700	17,700	13,300	62,400	4.7	13
- storm	19	1		1,800	1,800	500	51,800	103.6	23
- combined	20	1		10,400	10,400	624	76,960	123.3	30
Wolf Creek	21,22	1		18,305	18,305	10,000	22,302	2.2	10
Rock Creek	23,24	1		41,986	41,986	23,300	26,644	1.1	4
Fremont - municipal	25	1		28,200	28,200	21,200	47,382	2.2	9
- storm	26	1		350	350	90	10,360	115.1	26
- combined	27	1		12,300	12,300	738	91,020	123.3	28
Lower Sandusky	28,29	1		34,877	34,877	19,400	22,334	1.2	6
TOTAL				420,416	420,416		705,342		
					Subtotal	232,767			

a_i: Effective Transmission from Source to River Mouth (usually 1.0).
b_i: Portion of parameter that is judged to be biologically available.
$c_i = a_i$
$d_i = a_i \times b_i \times c_i$: Load at the mouth with losses and availability factored in.
$d_i \times a_i \times b_i$ (Stage I), or $= e_i \times a_i \times b_i$ (Stage II).

$f_i = g_i$ (Stage I), or h_i (Stage II.
$g_i = f_i \div e_i$
h_i: The rank from smallest to largest value in g_i (cost-effectiveness).

Cost-Effectiveness Analysis

Total P

Worksheet 7 (Continued)

Source	Column ➤ Position	a, Effective Transmission × Bio-Available Fraction	b,	c, Total Load to Surface Water (kg/yr)	d, Load at Mouth (kg/yr)	e, Load Reduction at Mouth (kg/yr)	f, Cost of Program ($/yr)	g, Cost Per Unit Removed at Mouth ($/kg)	h, Cost-Effective Rank
STAGE II						STAGE II	STAGE II	STAGE II	
Loss Creek	1,2					5,700	569,400	99.9	21
Bucyrus - municipal	3					1,672	48,600	29.1	16
- storm	4					58	11,180	192.7	38
- combined	5					1,555	177,840	114.4	34
Broken Sword	6,7					6,000	561,600	93.6	20
Upper Sandusky River	8,9					10,400	823,800	79.2	18
Upper Sandusky -municipal	10					1,064	22,500	21.1	15
-combined	11					402	165,490	411.7	40
Tymochtee Creek	12,13					14,600	1,585,200	108.6	25
Middle Sandusky	14,15					18,800	1,627,200	86.6	19
Honey Creek	16,17					8,200	1,030,800	125.7	32
Tiffin - municipal	18					2,189	93,600	42.8	17
- storm	19					320	60,200	188.1	35
- combined	20					2,496	256,880	102.9	31
Wolf Creek	21,22					5,400	1,029,300	190.6	37
Rock Creek	23,24					12,100	1,229,700	101.6	22
Fremont - municipal	25					3,476	71,028	20.4	14
- storm	26					64	12,040	188.1	36
- combined	27					2,952	303,810	102.9	29
Lower Sandusky	28,29					9,700	1,030,800	106.3	24
					Subtotal	107,148	10,710,902		
				STAGE I	Subtotal	232,767			
				STAGE II	Subtotal	107,148			
					TOTAL	339,915			

a,: Effective Transmission from Source to River Mouth (usually 1.0).
b,: Portion of parameter that is judged to be biologically available.
c, = a,
d, = a, × b, × c,: Load at the mouth with losses and availability factored in.
e, = d, × a, × b, (Stage I), or = e, × a, × b, (Stage II).
f, = g, (Stage I), or h, (Stage II.
g, = f, ÷ e,
h,: The rank from smallest to largest value in g, (cost-effectiveness).

Summary of Programs

Worksheet 8

Sources	Column ►	a_n	b_n	c_n	d_n	e_n
	Rank (h_n)	Stage	Load Reduction (kg/yr)	Σ Load Reduction (kg/yr)	% Reduction	Cost of Reduction ($/yr)	Σ Reduction Costs ($/yr)
Combined Sewer - Tiffin	31	II	2,496	323,381	77	256,380	8,825,300
Cropland - Honey Creek	32	II	8,200	331,581	79	1,030,800	9,856,600
Combined Sewer - Bucyrus	33	I	409	331,990	79	53,280	9,909,880
Combined Sewer - Bucyrus	34	II	1,555	333,545	79	177,840	10,087,720
Storm Sewer - Tiffin	35	II	320	333,865	79	60,200	10,147,920
Storm Sewer - Fremont	36	II	64	333,929	79	12,040	10,159,960
Cropland - Wolf Creek	37	II	5,400	339,329	81	1,029,300	11,189,260
Storm Sewer - Bucyrus	38	II	58	339,387	81	11,180	11,200,440
Combined Sewer - Upper Sandusky	39	I	126	339,513	81	49,580	11,250,020
Combined Sewer - Upper Sandusky	40	II	402	339,915	81	165,490	11,415,510

$a_n = e_n$
$b_n = \Sigma a_n$
$c_n = b_n + d_n$ (total)
$d_n = f_n = g_n$
$= \Sigma d_n$

Summary of Programs

Worksheet 8

Sources	Column ➤	a_n	b_n	c_n	d_n	e_n
	Rank (h_n)	Stage	Load Reduction (kg/yr)	Σ Load Reduction (kg/yr)	% Reduction	Cost of Reduction ($/yr)	Σ Reduction Costs ($/yr)
Cropland - Upper Sandusky	1	I	21,200	21,200	5	17,849	17,849
Cropland - Middle Sandusky	2	I	38,100	59,300	14	35,256	53,105
Cropland - Broken Sword	3	I	11,700	71,000	17	12,168	65,273
Cropland - Rock Creek	4	I	23,300	94,300	22	26,644	91,917
Cropland - Tymochtee	5	I	29,600	123,900	29	34,346	126,263
Cropland - Lower Sandusky	6	I	19,400	143,300	34	22,334	148,597
Cropland - Loss Creek	7	I	10,000	153,300	36	12,337	160,934
Cropland - Honey Creek	8	I	15,800	169,100	40	22,334	183,268
Municipal - Fremont	9	I	21,200	190,300	45	47,352	230,620
Cropland - Wolf Creek	10	I	10,000	200,300	48	22,302	252,922
Municipal - Upper Sandusky	11	I	6,200	206,500	49	15,000	267,922
Municipal - Bucyrus	12	I	10,400	216,900	52	32,400	300,322
Municipal - Tiffin	13	I	13,300	230,200	55	62,400	362,722
Municipal - Fremont	14	II	3,476	233,676	56	71,028	433,750
Municipal - Upper Sandusky	15	II	1,064	234,740	56	22,500	456,250
Municipal - Bucyrus	16	II	1,672	236,412	56	48,600	504,850
Municipal - Tiffin	17	II	2,189	238,601	57	93,600	598,450
Cropland - Upper Sandusky	18	II	10,400	249,001	59	823,800	1,422,250
Cropland - Broken Sword	19	II	18,800	267,801	64	1,627,200	3,049,450
Cropland Middle Sandusky	20	II	6,000	273,801	65	561,600	3,611,050
Cropland - Loss Creek	21	II	5,700	279,501	66	569,400	4,180,450
Cropland - Rock Creek	22	II	12,100	291,601	69	1,229,700	5,410,150
Storm Sewer - Tiffin	23	I	500	292,101	69	51,800	5,461,950
Cropland - Lower Sandusky	24	II	9,700	301,801	72	1,030,000	6,491,950
Cropland - Tymochtee	25	II	14,600	316,401	75	1,585,200	8,077,150
Storm Sewer - Fremont	26	I	90	316,491	75	10,360	8,087,510
Storm Sewer - Bucyrus	27	I	80	316,571	75	9,620	8,097,130
Combined Sewer - Fremont	28	I	738	317,304	75	91,020	8,188,150
Combined Sewer - Fremont	29	II	2,952	320,261	76	303,810	8,491,960
Combined Sewer - Tiffin	30	I	624	320,885	76	76,960	8,568,920

$a_n = e_n$
$b_n = \Sigma a_n$
$c_n = b_n \div d_n$ (total)
$d_n = f_n = g_n$
$e_n = \Sigma d_n$

Appendix F
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abbreviations/conversion factors

Abbreviations

ac	acres
cap	capita
Σ	summation of . . . .
gal	gallon
ha	hectares
kg	kilograms
km^2	square kilometers
L	liters
lb	pound
mg	milligrams
mgd	million gallons per day
mt	metric tons
mi^2	square miles
yr	year
T	tons (short)

Conversion Factors

To Convert	*To Obtain*	*Multiply By*
ac	ha	0.4047
kg	mg	1,000,000
km^2	ha	100
lb	kg	0.4536
lb	mt	0.004535
mgd	L/day	3,785,000
mi^2	ha	259.0
mi^2	km^2	2.59
mt	kg	1000.0
T	kg	907.2
T	mt	0.9072

Miscellaneous

mgd × mg/L × 1,382 = kg/yr

T/ac/yr × 224.3 = mt/km^2/yr

1.0 mg/L ≅ 3.8 kg/million gal ≅ 8.3 lb/million gal